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IP Research assignment

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Computer Science (EEMCS)

Design and Analysis of Communication Systems (DACS)

Evaluating the Impact of Large Vehicles in Vehicular
Communication

Yu Qiao

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Supervisors:

Dr.ir. Georgios Karagiannis

M.Sc. Wouter Klein Wolterink

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1. Introduction

In this chapter, a general background of the car-to-car communication is given first. Furthermore, specific description about the project is provided, including project-specific background, problem statement, and research questions.

1.1 General Background

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 V2V communication approach supports the communication between vehicles, while Vehicle to Infrastructure (V2I) communication approach supports the communication between Vehicles and Infrastructure. The proposed technology to perform this information exchange is the IEEE 802.11p technology [IEEE802.11p-2010], 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., [KaA11]. 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 [EiSc06]. Therefore, it becomes more and more important to ensure accurate wave propagation in VANETs. Figure 1 shows a scenario, where a car accident occurred in an intersection, and where VANET is used as a V2V communication network to inform vehicles in the neighborhood about this accident. With such benefits, researches are motivated to study the behaviors of vehicles and vehicular networks.

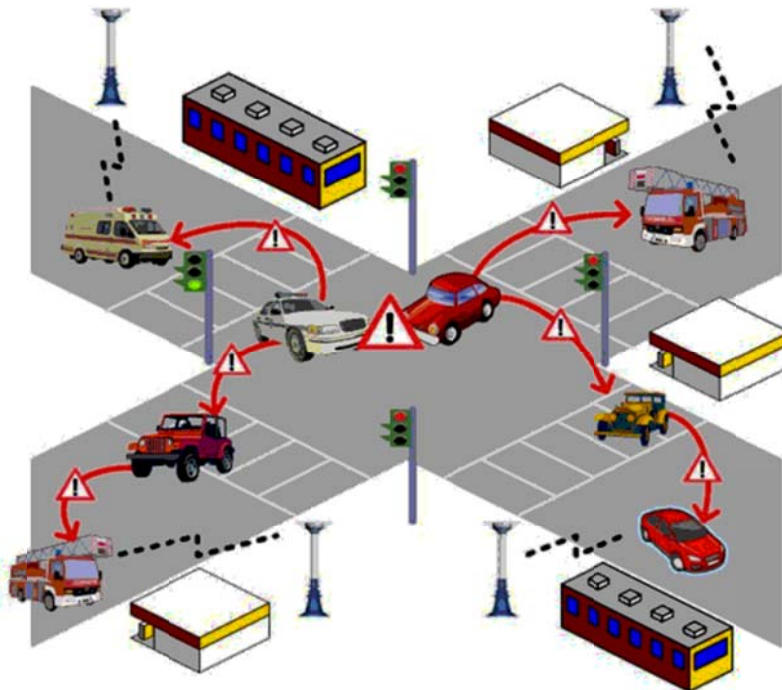


Figure 1. Vehicle Ad hoc Networks, copied from [POSTECH]

VANET supports data communications among nearby vehicles and between vehicles and nearby fixed infrastructure, generally represented as roadside entities. VANET turns every participating car into a wireless node, allowing cars to connect to each other and, in turn, create a network with a wide range. As cars fall out of the signal range and drop out of the network, other cars can join in, connecting vehicles to one another so that a mobile Internet is created.

1.2 Project-specific Background

Since Vehicle-to-Vehicle (V2V) communication is proposed as the communication paradigm for a number of traffic safety, traffic management, and infotainment applications, this project focuses on V2V communication. In V2V communication, the relatively low heights of the antennas on communicating entities imply that the optical line of sight (LOS) can easily be blocked by an obstruction, either static (e.g., buildings, hills) or mobile (other vehicles on the road). There exists a wide variety of experimental studies dealing with the propagation aspects of V2V communication. Many of these studies deal with static obstacles, often identified as the key factors affecting signal propagation (see [BaKr06] [ChCa05]). However, it is reasonable to expect that a significant portion of the V2V communication will be bound to the road surface, especially in highway environment, thus making the LOS between two communicating nodes susceptible to be interrupted by other vehicles. It has been shown in some papers that other non-communicating vehicles often block the LOS between the communicating vehicles, thus significantly attenuating the signal. This results in a significant reduction in the received power level and effective communication range [MeBo10] [BoVi11].

In this assignment, more attention will be paid to the impact of the height of vehicles, when they are used as transmitter, receiver or obstacle.

1.3 Problem Statement

When one wants to study such applications, for instance using simulation, a very basic need is to have a realistic model for how electromagnetic waves propagate through the air. What percentage of 802.11-packets will arrive when two cars are separated by a predefined distance? How do other cars, bridges, and buildings alongside the road influence propagation? Thus propagation effects when vehicles are communicating should be analyzed, e.g. reflection, diffraction effects. Current models either consider few effects or take all of these effects into account but with much high computation complexity. In order to evaluate the impact of vehicles as obstacles, a model needs to be used that accounts for vehicles as three-dimensional obstacles and take into account their impact on the electromagnetic wave propagation. In particular, realistic propagation models need to be used that can model certain propagation effects, such as reflection and diffraction effects. Such a model is proposed by Boban et al. in [BoVi11] and [BoMe11], which quantifies the effect of vehicles on LOS and consequently on the received power level. However, their performed simulation experiments are rather limited in scope, i.e., the road topology is based on the Portuguese highway A28 environment, where vehicle topology and vehicle density is defined in a deterministic manner. Moreover, the exact positions and dimensions of vehicles are provided by snapshots obtained from aerial photography, which can only represent specific cases from the road traffic data sets.

1.4 Research Questions

Motivated by above, this assignment uses in the simulation experiments a propagation model that can be applied in V2V communications scenarios, when the communication: 1) is using 802.11p Dedicated Short Range Communication (DSRC) standard, 2) consider vehicles as obstructions. Further more, this report extends the research work accomplished in [BoVi11] and [BoMe11], with extensive simulation studies in which (i) the effect of Large vehicles on V2V communication and (ii) the benefit of choosing

a Large vehicle as a next hop are investigated when different road topologies, vehicle densities, percentages of Large vehicles, transmission power, and DSRC data rates (i.e., modulation types and minimum sensitivity threshold) are used. The research questions that have to be answered by this assignment are:

- 1) What is the impact of Large vehicles in V2V communication, when these are used as senders, obstacles or receivers?
- 2) What is the impact of Large vehicles on multi-hop V2V communication, when these are selected as next hops?

The network environment in simulation is determined according to the propagation model we choose. Then by defining several scenarios in the network environment, e.g. with different vehicle density and vehicle types, the research questions could be answered in analysis about simulation results.

1.5 Outline of this report

This report is organized as follows. Chapter 2 presents the simulation environment, simulation topology in our experiments, and describes the propagation model implemented in the simulation, including the implementation and verification. In Chapter 3, an introduction to the performance measurements in the experiments is given first. Then different scenarios in simulation are determined based on the research goal in this assignment. And the simulation results are obtained and analyzed. In the end, Chapter 4 concludes the assignment and gives future work.

2. Simulation Environment and Models

In this chapter, the simulation environment used in our assignment is introduced firstly. Next, the network topology implemented in the simulation for our experiments is described. Then, in section 2.3, the propagation model used to clarify channel characterization in V2V communication is analyzed, including the selection, implementation and verification.

2.1 Simulation Environment

For the simulations accomplished in this research work the OMNeT++ network simulator v4.1 [Omnetpp] combined with the MiXiM framework v2.1 [MiXiM] is 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 [IEEE802.11p-2010].

2.1.1 OMNET++

OMNeT++ (Objective Modular Network Tested in C++) is an extensible and modular component-based C++ simulation library and framework that is running on different operating systems such as Linux, Mac OS X, Unix-like systems and Windows. Primarily, OMNET++ is developed for building network simulators. The simulator can be used for traffic modeling of telecommunication networks, protocol modeling, queuing networks modeling, multiprocessors and other distributed hardware systems modeling, hardware architectures validating, evaluating performance aspects of complex software systems and modeling any other systems where the discrete event approaches are suitable [Omnetpp].

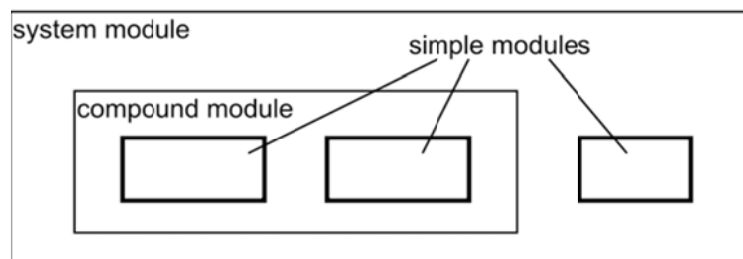


Figure 2. Component-architecture for models in OMNeT++ [Omnetpp_manual]

OMNeT++ provides a component-architecture for models. These components programmed in C++ are nested hierarchically and simpler components can assemble to compound components and models using a high-level language—NED (Network Description), see Figure 2. NED lets the user declare simple modules, and connect and assemble them into compound modules. The user can label some compound modules as networks. These compound models are self-contained simulation models. Communication channels can be defined as another component type, whose instances can also be used in compound modules. The NED language has several features which let it scale well. Therefore, it can be used to model large communication topologies [Omnetpp_manual]. These features are:

- Hierarchical: The traditional way to deal with complexity is by introducing hierarchies. Any module which would be too complex as a single entity can be broken down into smaller modules, and used as a compound module.
- Component-Based: Simple modules and compound modules are inherently reusable, which not only reduces code copying, but more importantly, allows component libraries (like MiXiM) to be reused.

- Interfaces: Module and channel interfaces can be used as a placeholder where normally a module or channel type would be used, and the concrete module or channel type is determined at network setup time by a parameter.
- Inheritance: Modules and channels can be subclassed.
- Packages: The NED language features a Java-like package structure, to reduce the risk of name clashes between different models.
- Inner types: Channel types and module types used locally by a compound module can be defined within the compound module, in order to reduce namespace pollution.
- Metadata annotations: It is possible to annotate module or channel types, parameters, gates and submodules by adding properties.

Reusability of models makes building certain models flexible. Also, the depth of module nesting is not limited, which allows the user to reflect the logical structure of the actual system in the model structure. In particular modules:

- can communicate with message passing. Messages can contain arbitrarily complex data structures.
- can send messages either directly to their destination or along a predefined path, through gates and connections.
- can have parameters which are used for three main purposes: to customize module behaviour; to create flexible model topologies (where parameters can specify the number of modules, connection structure etc); and for module communication, as shared variables.
- at the lowest level of the module hierarchy are to be provided by the user, and they contain the algorithms in the model.

During simulation execution, simple modules appear to run in parallel, since they are implemented as co-routines (sometimes termed lightweight processes). To write simple modules, the user does not need to learn a new programming language, but he/she is assumed to have some knowledge of C++ programming.

Therefore, an OMNeT++ model is combined by simple modules by using the NED language while the simple modules themselves are programmed in C++. The simulation system provides two components: simulation kernel containing the code that manages the simulation and the simulation class library; user interfaces. Graphical, animating user interfaces are highly useful for demonstration, while command-line user interfaces are best for batch execution.

Thus, the way of how OMNeT++ is used is as follows. First, the NED files are compiled into C++ source code, using the NEDC compiler which is part of OMNeT++. Then all C++ sources are compiled and linked with the simulation kernel and a user interface to form a simulation executable.

2.1.2 MiXiM

MiXiM (a MiXed siMulator) is an OMNeT++ modelling framework created for mobile and fixed wireless networks, such as wireless sensor networks, body area networks, ad-hoc networks, vehicular networks, etc. [MiXiM]. MiXiM provides detailed models and protocols, as well as a supporting infrastructure. These can be divided into five groups [KöSw08]:

- Environment models: in a simulation, only relevant parts of the real world should be reflected, such as obstacles that hinder wireless communication.

- Connectivity and mobility: when nodes move, their influence on other nodes in the network varies. The simulator has to track these changes and provide an adequate graphical representation.
- Reception and collision: For wireless simulations, movements of objects and nodes have an influence on the reception of a message. The reception handling is responsible for modeling how a transmitted signal changes on its way to the receivers, taking transmissions of other senders into account.
- Experiment support: the experimentation support is necessary to help the researcher to compare the results with an ideal state, help him to find a suitable template for his implementation and support different evaluation methods.
- Protocol library: last but not least, a rich protocol library enables researchers to compare their ideas with already implemented ones.

The base framework of MiXiM provides the general functionality needed for almost any wireless modeling. And since every module in OMNeT++ can be replaced, we can easily implement another module using different protocol.

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 [IEEE802.11p-2010]. In particular, the used carrier frequency is set to 5.9 GHz. The header length in each layer becomes different from the Mac80211 example used in [MiXiM].

2.2 Simulation Topology

The road topology used in [BoVi11] is the Portuguese highway A28, which is a north-south motorway with length of 12.5km. Due to the fact that the aerial photography of the Portuguese highway A28 in [BoVi11] limits the analysis to only a predefined vehicle density with a certain percentage of Large vehicles we decided to use another type of simulation topology where a variety of scenarios can be evaluated.

The topology used in the performed simulations is a 4 lane road, see Figure 3. Note that a bold black line in Figure 3 represents the center of a lane. The length of this road is 5 Km. The inter-lane distance is defined according to Trans-European North-South Motorway (TEM) Standards [TEM]. The used values are shown in Figure 3. In order to avoid border effects, the torus (set parameter 'useTorus' to true) topology is used in simulations, meaning 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 2.5km.

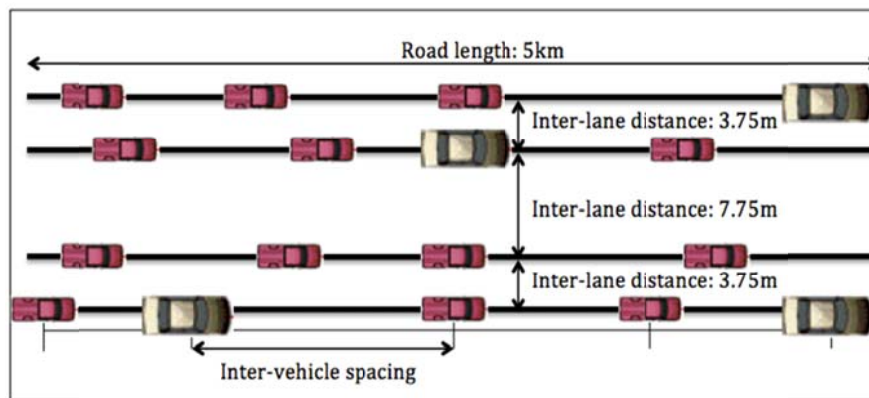


Figure 3. Simulation topology

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 [BoVi11]
- *type of vehicles*: two types of vehicles are distinguished, Large (or tall), and Small (or short) vehicles, see [BoVi11]
- *dimensions of vehicles*: this represents the length, width and height of both Large and Small vehicles, see Table 1. These dimensions are random variables, but their values are set before placing the vehicles on the road.

The vehicles are carrying transmitter/receiver antennas on their roofs, see [BoVi11]. In particular, each Small vehicle is carrying one antenna that is located on top of the vehicle and in the middle of the roof. Each Large vehicle is carrying two antennas on the roof, one in the front and another in the back of the vehicle, see [BoMe11]. The height of each antenna is set to 10 cm and the antenna gain is set to 3dBi.

Table 1. Dimension of vehicles

Type	Parameters	Estimate
Small	Width	Mean: 175cm; Std. deviation: 8.3cm
	Height	Mean: 150cm; Std. deviation: 8.4cm
	Length	Mean: 500cm; Std. deviation: 100cm
Large	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 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.

2.3 Propagation Model

As indicated in previous sections, our assignment is an extension research to [BoVi11] and [BoMe11]. The simulation experiments for evaluating the impact of Large vehicles in V2V communication in this assignment are based on the propagation model proposed in [BoVi11] (also used in [BoMe11]). Section 2.3.1 firstly describes propagation effects in V2V communication. Next, the reason that we use the propagation model in [BoVi11] is given in section 2.3.2, which also introduces the channel characteristics considered in the model. Then the detailed methodology for quantifying the impact of vehicles as obstacle on LOS and consequently on the received signal power in the propagation model is discussed in section 2.3.3. At last, the verification for the propagation model is given in section 2.3.4.

2.3.1 Propagation Effects

The simplest basic mechanism that governs the propagation of electromagnetic waves is free space propagation – in other words, one transmitting and one receiving antenna in free space. In a more realistic scenario, there are dielectric and conducting obstacles (Interacting Objects (IOs)). If these IOs have a smooth surface, waves are reflected and a part of the energy penetrates the IO (transmission). If

the surfaces are rough, the waves are diffusely scattered. Finally, waves can also be diffracted at the edges of the IOs. The main effects will now be discussed one after the other, see e.g., [WirelessComm.11].

When reflection occurs, a portion of the transmitted signal will be reflected back to the transmitting device rather than continuing to the receiver. The ratio of energy bounced back depends on the impedance mismatch. Mathematically, it is defined using the reflection coefficient. Figure 4 shows reflection and transmission.

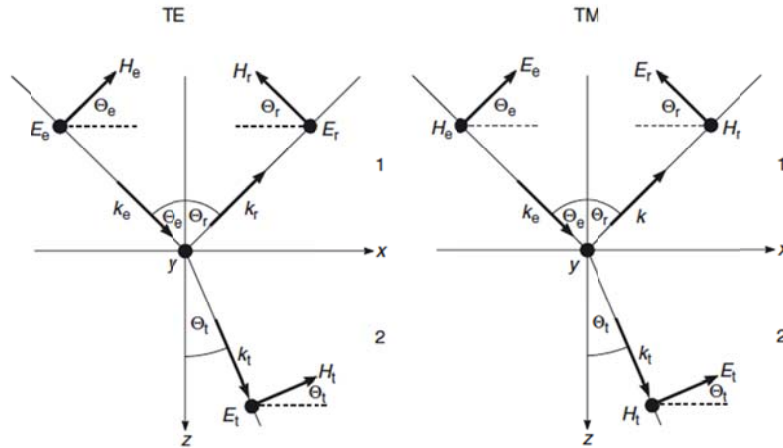


Figure 4. Reflection and transmission, copied from [WirelessComm.11]

In electromagnetic wave propagation, the knife-edge effect or edge diffraction is a redirection by diffraction of a portion of the incident radiation that strikes a well-defined obstacle such as a mountain range or the edge of a building. The knife-edge effect is explained by Huygens-Fresnel principle, which states that a well-defined obstruction to an electromagnetic wave acts as a secondary source, and creates a new wavefront. This new wavefront propagates into the geometric shadow area of the obstacle. Figure 5 shows the Huygen's principle. The impact of an obstacle can also be assessed qualitatively, and intuitively, by the concept of Fresnel zones. Figure 6 shows the basic principle. Draw an ellipsoid whose foci are the BS and the MS locations. According to the definition of an ellipsoid, all rays that are reflected at points on this ellipsoid have the same run length (equivalent to runtime). The eccentricity of the ellipsoid determines the extra run length compared with the LOS – i.e., the direct connection between the two foci. Ellipsoids where this extra distance is an integer multiple of $\lambda/2$ are called “Fresnel ellipsoids”.

Scattering is a general physical process where some forms of radiation, such as light, sound, or moving particles, are forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which they pass. Scattering is often caused by rough surface (figure 7).

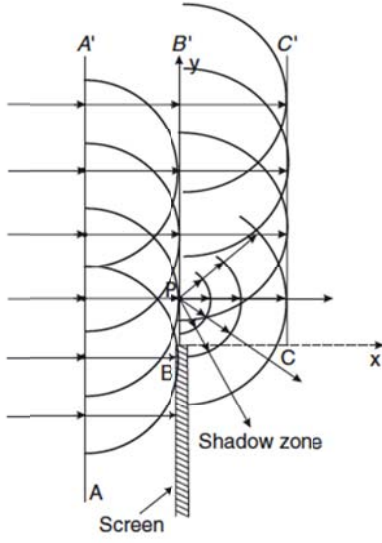


Figure 5. Huygen's principle

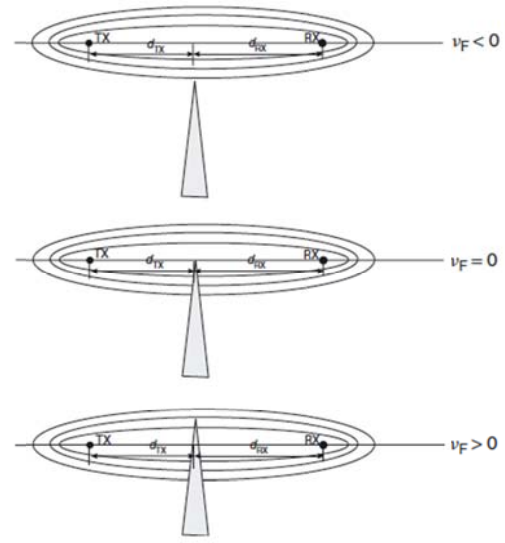


Figure 6. Basic concept of Fresnel zones

Both copied from [WirelessComm.11]

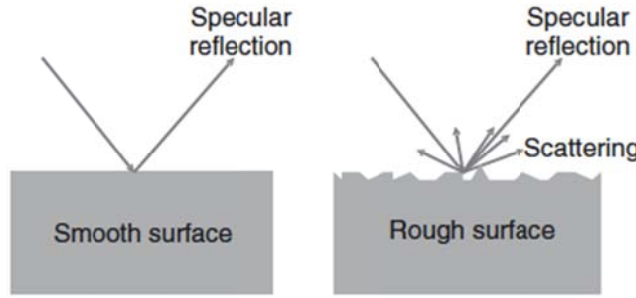


Figure 7. Scattering, copied from [WirelessComm.11]

2.3.2 Model Selection

This assignment concentrates on the statistical variations of the channel gain (the signal strength) in the V2V communication, thus the models analyzing other effects (for example, delay dispersion) are not included. In this section, first we only consider basic models related to the propagation effects mentioned in section 2.3.1, including Free Space Model, Reflection Model, Diffraction Model, and Scattering Model. Then, more complicated models for wireless channels are discussed.

The Free Space Model is only suitable for the simplest scenario: a transmit and a receive antenna in free space. Energy conservation dictates that the integral of the power density over any closed surface surrounding the transmit antenna must be equal to the transmitted power. According to Friis' law, the received power P_{RX} as a function of the distance d in free space is:

$$P_{RX}(d) = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi d} \right)^2 \quad (1)$$

The factor $(\lambda / 4 \pi d)^2$ is also known as the free space loss factor. Another extensional model considering the received field strength, averaged over both small-scale and the large-scale fading, is the 'breakpoint' model (with the $n = 2$ valid for distance up to $d < d_{break}$, and $n = 4$ beyond that).

Reflection Model refers to the two-ray ground reflection model. This model considers both the direct path and a ground reflection path. This is also known as the d-4 power law, says that the received signal power is inversely proportional to the fourth power of the distance between Tx and Rx. The following equation is derived in [WirelessComm.11].

$$P_{RX}(d) \approx P_{TX} G_{TX} G_{RX} \left(\frac{h_{TX} h_{RX}}{d^2} \right)^2 \quad (2)$$

where h_{TX} and h_{RX} are the height of the transmit and the receive antenna, respectively; it is valid for distances larger than:

$$d_{break} \gtrsim \frac{4h_{TX}h_{RX}}{\lambda}$$

For distances $d < d_{break}$, Friis' law remains approximately valid.

Diffraction effects include diffraction over spherical earth, diffraction over isolated obstacles, diffraction by thin screens, and diffraction over wedges. Here we only explain models for diffraction over obstacles, including knife-edge model and rounded-obstacle model. In knife-edge model, every obstacle (either single or multiple) is regarded as a knife-edge. While in rounded-obstacle model, the radius R of the rounded obstacle is a parameter in calculating the attenuation caused by diffraction. The attenuation now has two parts: the knife-edge attenuation of the measured vertex, and the additional attenuation with the parameter R .

Scattering theory usually assumes roughness to be random. However, in wireless communications it is common to also describe deterministic, possibly periodic, structures as rough. Two main theories have evolved: the Kirchhoff theory and the perturbation theory. The Kirchhoff theory is conceptually very simple and requires only a small amount of information – namely, the probability density function of surface amplitude (height). The theory assumes that height variations are so small that different scattering points on the surface do not influence each other. The perturbation theory generalizes the Kirchhoff theory, not only using the probability density function of the surface height but also taking into account the question “how fast does the height vary if we move a certain distance along the surface?”.

Table 2 gives a comparison of the models mentioned above, in terms of propagation effects consideration. For the reason that our project goal includes studying impacts of obstructions in V2V communication, we add another comparison metric: obstacle consideration (‘Obstacles’ in the table, means whether the impact of obstacles is considered in the model).

Table 2. Comparison of basic models

Models Comparison Metrics	Basic models			
	Free Space Model (Path Loss Model)	Ground Reflection (Two-Ray) Model	Knife-Edge Model	Scattering Model
LOS	✓	✓		
Reflection		✓		
Diffraction			✓	
Scattering				✓
Obstacles			✓	✓
Complexity	Low	Low	Low	Low

The basic models mentioned above consider too few propagation effects and the complexities of them are too low so that they are not suitable for a realistic vehicular communication. Thus, more complicated models are discussed as follows.

Based on the approach of modeling the environment (geometrically or non-geometrically), and the distribution of objects in the environment (stochastic or deterministic), three main types of models were identified: non-geometrical stochastic models, geometry-based deterministic models, and geometry-based stochastic models. The following gives an overview of these models.

- Non-geometrical stochastic models, see e.g., [OtBu09][ChHe07][SeMa08]:
These propagation models are based on an extensive series of measurements. Each measurement represents an average of a set of samples. For a certain environment, predications of the signal transmission can be obtained based on a series of results, which are linked to the environment and parameters of the measurement. This reduces computational cost significantly. However, these models are not realistic. They can only be used over parameter ranges included in the original measurement set; otherwise, the predications are not accurate. A more detailed channel model is required in order to increase the accuracy of this model.
- Geometry-based deterministic models, see e.g., [BoVi11], [MaFü04], [LeBo11]:
Deterministic propagation models 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 [MaFü04]. 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., [BoVi11][LeBo11].
- Geometry-based stochastic models, see e.g., [KaTu09], [ChWa09]:
Geometry-based stochastic models are the combination of deterministic models and statistics of various parameters (information of environment). The propagation model proposed in [KaTu09] distributes the vehicles as well as other objects at random locations and analyzes four distinct signal components: LOS, discrete components from mobile objects, discrete components from static objects, and diffuse scattering. The propagation model proposed in [ChWa09] presented a MIMO channel model that takes into account the LOS, single-bounced rays and double-bounced rays by employing a combined two-ring and ellipse propagation model. By properly defining the parameters, this propagation model can be used in various V2V environments with varying vehicle densities.

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. Thus a geometry-based deterministic model with computation reduction is suitable for the research presented in this report. Considering geometry-based deterministic models, the propagation model in [MaFü04] encompasses all objects in the analyzed environment (both static and mobile) and evaluates the signal behavior by analyzing the strongest propagation paths between the communicating pair. However, the realism of this model is achieved at the expense of high computational complexity and location-specific modeling. The propagation model proposed in [LeBo11] presents a semi-

deterministic solution, which benefits from the advantages of both statistical and deterministic model. One parameter, bit error rate (BER), is used to show the quality of the communication link between two nodes. The search path is limited by ray tracing only to the direct path for the reason that the LOS path has the main impact on the received signal. However, LOS and non-LOS (NLOS) results are always either nearly perfect ($\sim 100\%$ of packets reach their destination) or poor ($\sim 0\%$ of packets reach their destination). This propagation model cannot accurately model the wave propagation between two vehicles, when another vehicle is located between them, i.e., obstacle. The research work proposed by Boban et al. in [BoVi11] 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 [BoVi11] 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 [BoVi11].

2.3.3 Model Implementation

This section gives a detailed description to the methodology used in the propagation model, see [BoVi11]. In [BoVi11], the aerial imagery is used to obtain road information of the Portuguese highway A28, including the exact position and length of vehicles. To ensure satisfactory accuracy, the width and height are determined from a Portuguese highway data set. Subsequently, the authors of [BoVi11] derived a way to analyze all possible connections between vehicles within a given range, by calculating LOS probability and received power level, as a two-step approach. Firstly, for LOS probability, the model determines the existence or non-existence of LOS based on the number and dimensions of vehicles potentially obstructing the direct path between vehicles designated as transmitter (Tx) and receiver (Rx). Secondly, 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 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 [ITU-R07]. When there are no vehicles obstructing the LOS between Tx and Rx, we use free space path loss model. If only one obstacle is located between Tx and Rx, then the single knife-edge model described in ITU-R recommendation [ITU-R07] 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 [ITU-R07], is used.

2.3.3.1 LOS Probability

The proposed model in [BoVi11] calculates the (non-) existence of the LOS for each link (i.e., between all communicating pairs) in a deterministic fashion, based on the dimensions of the vehicles and their locations. [BoVi11] derives the expressions for the microscopic (i.e., per-link and per-node) and macroscopic (i.e., system-wide) probability of LOS. It has to be noted that, from the electromagnetic wave propagation perspective, the LOS is not guaranteed with the existence of the visual sight line between the Tx and Rx. It is also required that the Fresnel ellipsoid is free of obstructions. Any obstacle that obstructs the Fresnel ellipsoid might affect the transmitted signal. As the distance between the transmitter and receiver increases, the diameter of the Fresnel ellipsoid increases accordingly. Besides the distance between the Tx and Rx, the Fresnel ellipsoid diameter is also a function of the wavelength.

To calculate $P(LOS)_{ij}$, i.e., the probability of LOS for the link between vehicles i and j , with one vehicle as a potential obstacle between Tx and Rx (of height h_i and h_j , respectively), we have:

$$P(LOS|h_i, h_j) = 1 - Q\left(\frac{h - \mu}{\sigma}\right) \quad (3)$$

and

$$h = (h_j - h_i) * \left(\frac{d_{obs}}{d}\right) + h_i - 0.6 * r_f + h_a \quad (4)$$

where the i, j subscripts are dropped for clarity, and h denotes the effective height of the straight line that connects Tx and Rx at the obstacle location when we consider the first Fresnel ellipsoid. Furthermore, $Q(\cdot)$ represents the Q-function, μ is the mean height of the obstacle, σ is the standard deviation of the obstacle's height, d is the distance between the transmitter and receiver, d_{obs} is the distance between the transmitter and the obstacle, h_a is the height of the antenna, and r_f is the radius of the first Fresnel zone ellipsoid which is given by

$$r_f = \sqrt{\frac{\lambda * d_{obs} * (d - d_{obs})}{d}}$$

with λ denoting the wavelength. We use the appropriate λ for the proposed standard for VANET communication (DSRC), which operates in the 5.9 GHz frequency band. As a general rule commonly used in literature, LOS is considered to be unobstructed if intermediate vehicles obstruct the first Fresnel ellipsoid by less than 40% [WirelessComm.11]. Furthermore, for No vehicles as potential obstacles between the Tx and Rx, we get (see Figure 8)

$$P(LOS|h_i, h_j) = \prod_{k=1}^{N_o} [1 - Q\left(\frac{h_k - \mu_k}{\sigma_k}\right)] \quad (5)$$

where h_k is the effective height of the straight line that connects Tx and Rx at the location of the k -th obstacle considering the first Fresnel ellipsoid, μ_k is the mean height of the k -th obstacle, and σ_k is the standard deviation of the height of the k -th obstacle. Provided that the heights of the obstacles are known beforehand (instead of being drawn from a normal distribution), equations (1) and (3) become deterministic (i.e., the result is zero in case of LOS obstruction and one otherwise).

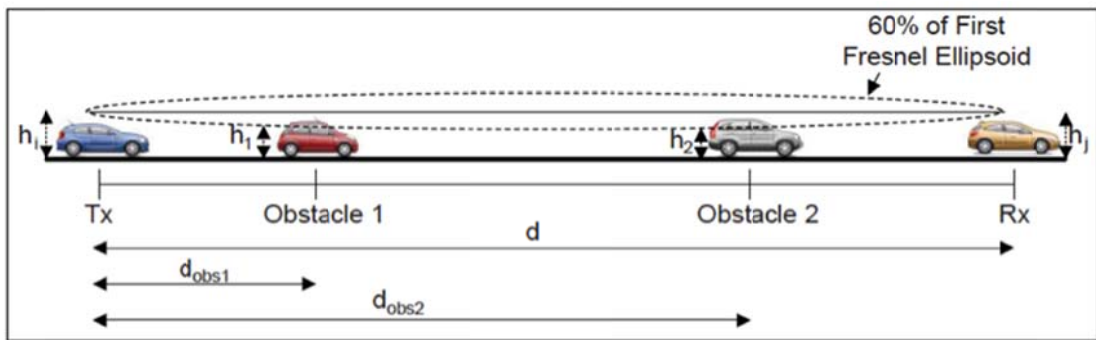


Figure 8. LOS consideration for a given link, copied from [BoVi11]

Averaging over the transmitter and receiver antenna heights with respect to the road, we obtain the unconditional $P(LOS)_{ij}$

$$P(LOS)_{ij} = \iint P(LOS|h_i, h_j) * p(h_i) * p(h_j) dh_i dh_j \quad (6)$$

where $p(h_i)$ and $p(h_j)$ are the probability density functions for the transmitter and receiver antenna heights with respect to the road, respectively.

The average probability of LOS for a given vehicle i , $P(LOS)_i$, and all its N_i neighbors is defined as

$$P(LOS)_i = \frac{1}{N_i} * \sum_{j=1}^{N_i} P(LOS)_{ij} \quad (7)$$

To determine the system-wide ratio of LOS paths blocked by other vehicles, we average $P(LOS)_i$ over all N_v vehicles in the system, yielding

$$\overline{P(LOS)} = \frac{1}{N_v} * \sum_{i=1}^{N_v} P(LOS)_i \quad (8)$$

2.3.3.2 Signal Attenuation

The attenuation on a radio link increases if one or more vehicles intersect the ellipsoid corresponding to 60% of the radius of the first Fresnel zone, independent of their positions on the Tx-Rx link (Figure 8). This increase in attenuation is due to the diffraction of the electromagnetic waves. The additional attenuation due to diffraction depends on a variety of factors: the obstruction level, the carrier frequency, the electrical characteristics, the shape of the obstacles, and the amount of obstructions in the path between transmitter and receiver. To model vehicles obstructing the LOS, we use the knife-edge attenuation model. It is reasonable to expect that more than one vehicle can be located between transmitter (Tx) and receiver (Rx). Thus, we employ the multiple knife-edge model described in ITU-R recommendation [ITU-R07]. When there are no vehicles obstructing the LOS between the Tx and Rx, we use the free space path loss model [WirelessComm.11].

1) Single Knife Edge

The simplest obstacle model is the knife-edge model, which is a reference case for more complex obstacle models (e.g., cylinder and convex obstacles). Since the frequency of DSRC radios is 5.9 GHz, the knife-edge model theoretically presents an adequate approximation for the obstacles at hand (vehicles). The prerequisite for the applicability of the model, namely a significantly smaller wavelength than the size of the obstacles [ITU-R07], is fulfilled (the wavelength of the DSRC is approximately 5 cm, which is significantly smaller than the size of the vehicles). The obstacle is seen as a semi-infinite perfectly absorbing plane that is placed perpendicular to the radio link between the Tx and Rx. Based on the Huygens principle, the electric field is the sum of Huygens sources located in the plane above the obstruction and can be computed by solving the Fresnel integrals. According to [ITU-R07], in the extremely idealized case, all the geometrical parameters are combined together in a single dimensionless parameter normally denoted by v , which may assume a variety of equivalent forms according to the geometrical parameters selected. A good approximation for the additional attenuation (in dB) due to a single knife-edge obstacle A_{sk} can be obtained using the following equation [ITU-R07]:

$$A_{sk} = \begin{cases} 6.9 + 20 * \log_{10} \left[\sqrt{(v - 0.1)^2 + 1} + v - 0.1 \right]; & \text{for } v > -0.7 \\ 0; & \text{otherwise} \end{cases} \quad (9)$$

where $v = \sqrt{2} * H / r_f$, H is the difference between the height of the obstacle and the height of the straight line that connects Tx and Rx, and r_f is the Fresnel ellipsoid radius. According to Fresnel zone geometry, r_f could be expressed as: $r_f = \sqrt{\frac{\lambda * d1 * d2}{d1 + d2}}$; $d1$ is the distance between transmitter and obstacle, and $d2$ is the distance between obstacle and receiver. H can be expressed as: $H = h_{IO} - h_{TX} - (h_{RX} - h_{TX}) * \frac{d1}{d1 + d2}$.

2) Multiple Knife Edge

The extension of the single knife-edge obstacle case to the multiple knife-edge is not straightforward. All of the existing methods in the literature are empirical and the results vary from optimistic to pessimistic approximations. The Epstein-Petterson method [EpPe53] presents a more optimistic view, whereas the Deygout [De66] and Giovanelli [Gi84] are more pessimistic approximations of the real world. Usually, the pessimistic methods are employed when it is desirable to guarantee that the system will be functional with very high probability. On the other hand, the more optimistic methods are used when analyzing the effect of interfering sources in the communications between transmitter and receiver. To calculate the additional attenuation due to vehicles, we employ the ITUR method [ITU-R07], which can be seen as a modified version of the Epstein-Patterson method, where correcting factors are added to the attenuation in order to better approximate reality.

To calculate additional attenuation due to multiple vehicles, the report is using ITU-R method from [ITU-R07], which can be seen as a modified version of Epstein-Patterson method.

According to [ITU-R07], two methods, Cascaded cylinder method and Cascaded knife edge method, are recommended for diffraction over irregular terrain which forms one or more obstacles to LOS propagation. The first one uses string analysis to find obstructions (several string points could be regarded as one obstruction), and assumes that each obstruction can be represented by a cylinder. Moreover, the second one corresponds to an empirical solution based on the supposition of knife-edge obstacles plus a correction to compensate for the higher loss due to a radius of curvature different from zero. The second one is based on the Deygout method limited to a maximum of 3 edges. As we have much more than 3 edges in some cases of the simulation, we decide to use cascaded cylinder method for the situation with multiple vehicles as obstacles.

In cascaded cylinder method, each vehicle as obstacle has a profile that contains height above sea level, distance from Tx, and distance to Rx. The first step is to perform a “stretched string” analysis of the profile. This identifies the sample points which would be touched by a string stretched over the profile from transmitter to receiver. For samples at spacings of 250 m or less any group of string points which are consecutive profile samples, other than the transmitter or receiver, should be treated as one obstruction. Figure 9 illustrates the geometry for an obstruction consisting of more than one string point. The following points are indicated by:

- w: closest string point or terminal on the transmitter side of the obstruction which is not part of the obstruct;
- x: string point forming part of the obstruction which is closest to the transmitter
- y: string point forming part of the obstruction which is closest to the receiver
- z: closest string point or terminal on the receiver side of the obstruction which is not part of the obstruction
- v: vertex point made by the intersection of incident rays above the obstruction.

The letters w, x, y and z will also be indices to the arrays of profile distance and height samples. For an obstruction consisting of an isolated string point, x and y will have the same value, and will refer to a profile point which coincides with the vertex. Note that for cascaded cylinders, points y and z for one cylinder are points w and x for the next, etc.

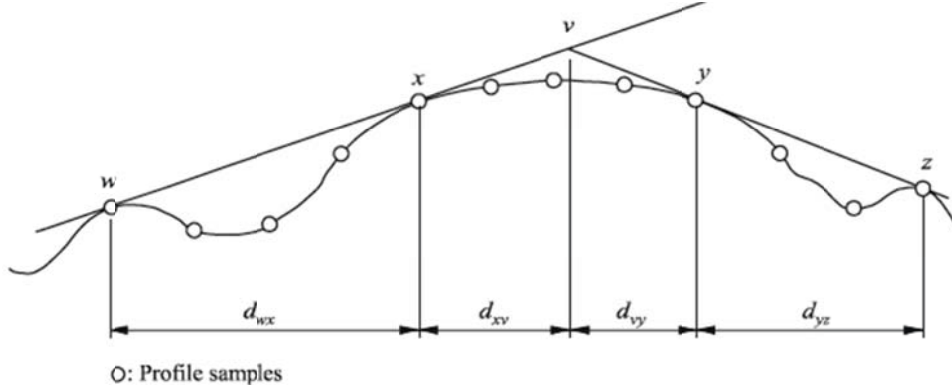


Figure 9. One obstruction consisting of multiple string points, copied from [ITU-R07]

Each obstruction is now modeled as a cylinder, as illustrated in Figure 10. A step-by-step method for fitting cylinders to a general terrain profile is described in [ITU-R07]. Each obstruction is characterized by w, x, y and z. The method is then used to obtain the cylinder parameters s1, s2, h and R (see Equations in [ITU-R07]). Figure 10 shows the cylinders.

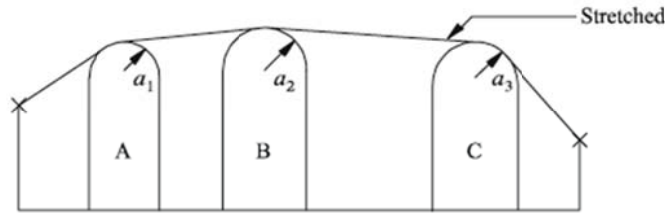


Figure 10. Obstructions modeled as cylinders, copied from [ITU-R07]

Having modelled the profile in this way, the diffraction loss for the path is computed as the sum of three terms:

- the sum of diffraction losses over the cylinders;
- the sum of sub-path diffraction between cylinders (and between cylinders and adjacent terminals);
- a correction term.

The total diffraction loss, in dB relative to free-space loss, may be written:

$$L_d = \sum_{i=1}^N L'_i + L''(wx)_1 + \sum_{i=1}^N L''(yz)_i - 20 \log C_N \quad \text{dB} \quad (10)$$

where:

- L'_i : diffraction loss over the i-th cylinder calculated by the method for single rounded obstacles, section 4.2 in [ITU-R07];
- $L''(wx)_1$: sub-path diffraction loss for the section of the path between points w and x for the first cylinder;
- $L''(yz)_i$: sub-path diffraction loss for the section of the path between points y and z for all cylinders;
- C_N : correction factor to account for spreading loss due to diffraction over successive cylinders.

Appendix 2 in [ITU-R07] gives a method for calculating L'' for each LOS section of the path between obstructions.

The correction factor, C_N , is calculated using:

$$C_N = (P_a/P_b)^{0.5} \quad (11)$$

where:

$$P_a = s_1 \prod_{i=1}^N [(s_2)_i] \left(s_1 + \sum_{j=1}^N [(s_2)_j] \right) \quad (12)$$

$$P_b = (s_1)_1 (s_2)_N \prod_{i=1}^N [(s_1)_i + (s_2)_i] \quad (13)$$

and the suffices to round brackets indicate individual cylinders.

2.3.4 Model Verification

As shown in [ITU-R07], the calculation for cascaded cylinder method is much more complicated than single knife-edge model. In single knife-edge model, all geometrical parameters are combined together into a single dimensionless parameter (normally denoted by v), and a good approximation for the additional attenuation (vs. v) can be obtained. However, in multiple cylinder method, no such single parameter can present all aspects that influence the attenuation. After ‘string analysis’ and modeling each obstruction as one cylinder, the diffraction loss for the path with multiple obstacles between Tx and Rx is computed as the sum of three terms: 1) the sum of diffraction losses over the cylinders (using rounded obstacle calculation), 2) the sum of sub-path diffraction between cylinders (and between cylinders and adjacent terminals), and 3) a correction term.

For single knife-edge model, we define three vehicles in simulator and vary their positions and height to achieve multiple cases with different values for v . The results showing the same trend of additional attenuation vs. v as the approximation in [ITU-R07] indicate the correction of implementation of single knife-edge model. For cascaded cylinder model, we define several cases to verify the calculation of the three terms in diffraction loss separately, since no approximation is provided as reference in [ITU-R07]. The case that multiple vehicles exist as one cylinder (vehicles as obstacles within 250m can be regarded as one obstruction/cylinder) between Tx/Rx and the vertex of the cylinder verifies the rounded obstacle method and the sub-path loss calculation. In other cases, more vehicles as potential obstacles between transmitter and receiver are defined, thus more cylinders exist between Tx and Rx. By defining different locations for vehicles as obstacle, we can obtain distinct positions for cylinders, thus verify calculation of both sub-path loss and correction factor. As to the method for finding vehicles as obstacles, we have verified for one lane and multiple lanes. Both showed the correction of implementation.

2.4 Conclusion

In this chapter, we have introduced simulation environment and simulation topology. Based on these, different scenarios can be defined in our experiments, which are described in Chapter 3. Besides, the methodology of the obstacle-aware propagation model has been given to quantify the impact of vehicles as obstacles, and the verification of the model indicates the correction of the implementation in our simulation. Based on these, different performance measurements are defined in Chapter 3. The experiments results for different scenarios and corresponding analysis are also shown in Chapter 3.

3. Experiment, Results and Analysis

The static parameters used in the simulated topology, such as road information, dimension of vehicles, antenna height are given in Section 2.2. However, different than [BoVi11], the percentage of Large vehicles, vehicles densities, transmission power, and DSRC data rates (i.e., modulation type and minimum sensitivity threshold) are varied to obtain different simulation scenarios.

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. 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 $\pm 5\%$ of the shown calculated mean values.

3.1 Performance Measurements

Four performance metrics are defined in order to investigate (i) the effect of Large vehicles on V2V communication and (ii) the benefit of choosing a Large vehicle as a next hop are investigated when different vehicle densities, percentages of Large vehicles, transmission power, DSRC data rates (i.e., modulation types and minimum sensitivity threshold) are used.

1. Average LOS Probability

The Average LOS Probability $\overline{P(LOS)}$ is defined as the average probability that each vehicle in the system can have a LOS to its neighbors in an observed range. In this simulation study, an observed range is a circular coverage area with a transmitting vehicle as center. Note however, that the observed range does not depend on the radio coverage area of a transmitter. The calculation method for average LOS probability has already been introduced in section 2.3.3.1.

2. Received Power Level

The Received Power Level is defined as the average value of the received powers at all the receiver vehicles under study (e.g., all Large or all Small vehicles in the system). This average value is expressed in dBm. The received power at each receiver is calculated by subtracting the signal attenuation, calculated by the propagation model (see section 2.3.3.2), from the transmitted power.

3. Packet Success Rate vs. Transmission Range

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. Note that the transmission range is different than the observed range, used for average LOS probability, due to the fact that the latter does not depend on 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 sensitivity thresholds defined for IEEE 802.11p are listed in Table 3. As can be seen in Table 3, each data rate requires a certain modulation type and a minimum sensitivity threshold. In our experiment, several DSRC data rates are considered.

Table 3. Requirements for DSRC receiver performance

Data Rate (Mb/s)	Modulation	Minimum sensitivity (dBm)
3	BPSK	-85
4.5	BPSK	-84
6	QPSK	-82
9	QPSK	-80
12	QAM-16	-77
18	QAM-16	-70
24	QAM-64	-69
27	QAM-64	-67

4. Ratio of Large vehicles selected as best next hop

The ratio of Large vehicles selected as best next hop is defined as the ratio of the total number of Large vehicles in the system, selected as best next hop to relay packets, divided by the total number of vehicles in the system. This performance measure is calculated using the steps defined in [BoMe11]:

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

3.2 Experiment Scenarios Description

In addition to the parameters used to emulate the IEEE 802.11p behavior and to determine the simulation topology in section 2.2, additional parameters are used to define different scenarios, which are specified in this section.

Based on the parameters described in section 2.2, we can see that there are 4 transmission types in the network: Small-Small, Small-Large, Large-Small, Large-Large. In order to study the impact of Large vehicles when varying vehicles density and the mixes of Large and Small vehicles, the scenarios 1 to 4 are defined, see Table 4.

In reality, generally the number of Small vehicles is larger than the number of Large vehicles. So we never define more than 50% for Large vehicles. Each Large vehicle percentage with six vehicle densities is defined as one scenario. Based on the two seconds time headway rule for driving on highway, we calculate the corresponding vehicle density as the reference (100% density in Table 4) for each scenario in the following way.

For a certain percentage (x) of Large vehicles, we can approximate the largest number of vehicles per kilometer on the highway by using highway 2s rule.

$$Density_{ref}(per\ lane) = \frac{1000}{(Dist_{2s} + vehLen_L) * x + (Dist_{2s} + vehLen_S) * (1-x)} \quad (veh/km) \quad (14)$$

$$Density_{ref}(four\ lanes) = 4 * Density_{ref}(per\ lane) \quad (veh/km)$$

$$Dist_{2s} = vehSpeed * 2 \text{ (m)}$$

For the reason that ‘vehicle density’ is hard to measure in the simulation, we vary the mean of the inter-vehicle spacing distribution to achieve the required vehicle densities values. By collecting total number of active vehicles within defined road length 5km, and dividing this number by 5 (km) and 4 (lanes), the vehicle density values in Table 4 are calculated.

Table 4. Parameters for determining scenarios

Large Vehicle Percentage	Inter-vehicle Spacing: Exponential Mean (Corresponded Density)					
	Density: 10%	25%	50%	75%	100%	125%
5% (Scenario 1)	500m (1.8veh/km/lane)	250m (3.7)	125m (7.9)	75m (11)	50m (17.5)	40m (20)
15% (Scenario 2)						
35% (Scenario 3)						
50% (Scenario 4)						

At last, in order to exploit the impact of Large vehicles used as next hop, we define scenario 5, in which we artificially vary the ratio of Large vehicles from 0.05 to 0.5 in order to analyze the benefits of selecting a Large vehicle depending on the relative number of Large vehicles on the road. We also vary the receiver sensitivity threshold based on the DSRC parameters for various data rates. The parameters for scenario 5 are shown in Table 5.

Table 5. Parameter for scenario 5

Density	7.9 veh/km/lane
Spacing Mean	125m
TX Power	10dBm (10 mW)
Large Vehicle Percentage	{0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.5 }
Sensitivity	{-65, -70, -77, -82, -85, -90, -95} dBm

For each of the scenarios 1, 2, 3 and 4 four transmission/reception types are applied, including (1) Tx and Rx are both Small vehicle (Small-Small), (2) both are Large vehicle (Large-Large), (3) Tx is Small vehicle while Rx is Large (Small-Large) and (4) Tx is Large vehicle while Rx is Small (Large-Small). Note that the vehicle density is indirect proportional to the inter-vehicle spacing, meaning that when the vehicle spacing is increasing then the vehicle density is decreasing and vice versa.

3.3 Evaluating the impact of Large vehicles used as Tx, Rx and obstacles

This section answers the first research question, by investigating what is the impact of Large vehicles in V2V communication, when these are used as senders, obstacles or receivers. In particular, three performance measures are observed: the *Average LOS Probability*, *Received Power Level* and *Packet Success Rate*. Moreover, the four transmission/reception types i.e., (Small-Small, Small-Large, Large-Small, Large-Large) are used.

The used propagation model for the investigation of the Average LOS Probability and the Received Power Level is the obstacle-aware propagation model described in Section 2.3.3 of this report. For the investigation of the Packet Success Rate the Free Space Path Loss model, see [WirelessComm.11], and the obstacle-aware propagation model are used.

3.3.1 Average LOS Probability

In this set of experiments the average LOS probability measure is investigated. Two types of experiments are performed.

The goal of the first type of experiments is to investigate the average LOS probability experienced when the four different transmission/reception types are used. In particular, the average LOS probability versus the observed range is investigated for the 4 transmission/reception types, see Figure 11. This is accomplished for Scenario 2, shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane.

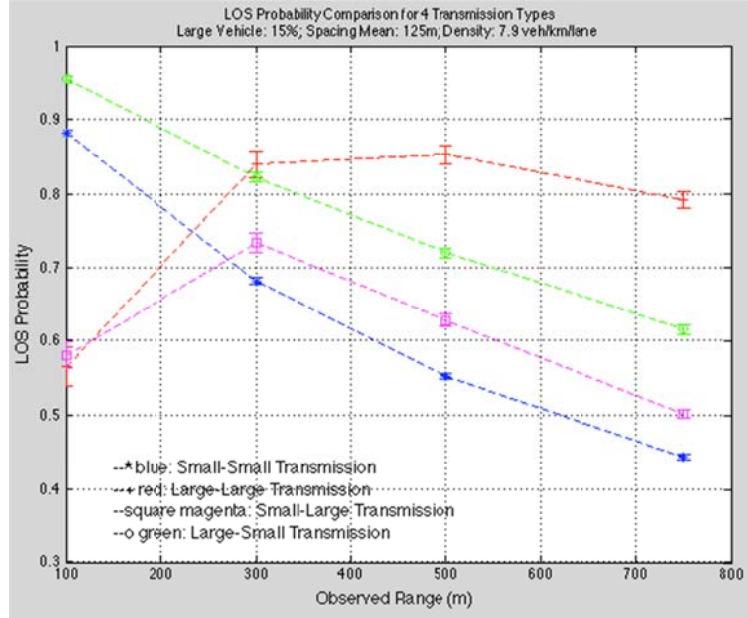


Figure 11. Average LOS probability comparison

From this type of experiments it can be concluded that the average LOS probabilities of the communication links with Large vehicles used as transmitter and/or receiver (i.e., Small-Large, Large-Small, Large-Large) are larger than the ones with Small vehicles used as both transmitter and receiver (i.e., Small-Small), when the observed range is over the 300m.

Within 100m observed range, the communication links with Large vehicles used as receivers (i.e., Small-Large, Large-Large) show a significantly lower average LOS probability than the ones with Small vehicles used as receivers (i.e., Small-Small, Large-Small). This is due to the fact that within an observed range of 100m, the Small-Large and Large-Large transmission/reception types use a small percentage of Large vehicle. This means that many transmitter vehicles cannot find any Large vehicle receivers within the observed range of 100m. This leads to the situation that $P(\text{LOS})$ defined in Eq. 7, becomes for these transmitter vehicles zero. Thus the average LOS Probability, defined in Eq. 8, decreases.

The goal of the second type of experiments is to investigate the average LOS probability for each transmission/reception type when different vehicle densities and Large vehicle percentages are used. In this type of experiments, the average LOS probability versus the observed range is investigated for the 4 transmission/reception types, see Figure 12. This is accomplished for Scenarios 1, 2, 3 and 4, shown in Table 4, for an observed range of 750m.

As the vehicle density increases, almost all the average LOS probability values become lower, see Figure 12. However, this conclusion is not valid for the communication links with Large vehicles used both as transmitter and receiver (i.e., Large-Large), when 5% Large vehicles and a Small vehicle density on the road are applied. This is caused due the low number of receiver Large vehicles.

For more realistic cases, with density larger than 7.9 veh/km/lane (inter-vehicle spacing smaller than 125m), it can be concluded that:

1. all the average LOS Probability values associated with the Large-Large transmission/reception type are higher than all the average LOS Probability values associated with all other transmission/reception types
2. all the average LOS Probability values associated with the Small-Small transmission/reception type are lower than all the average LOS Probability values associated with all other transmission/reception types
3. all the average LOS Probability values associated with the Large-Small transmission/reception type are higher than all the average LOS Probability values associated with the Small-Large transmission/reception types
4. average LOS probability for all transmission/reception types becomes smaller when the vehicle density increases. As the vehicle density increases, the electromagnetic wave is more probable obstructed by vehicles as being potential obstacles, which causes the decrease of the average LOS probability.
5. average LOS probability for all transmission/reception types becomes smaller when higher percentages of Large vehicles are used on the road. As the percentage of Large vehicles on the road increases, the average LOS Probability values associated with all the transmission/reception types slightly decreases. This slight decrease is due to the fact that although there will be more communication links using the Large-Large transmission/reception type (which increase the average LOS probability), a higher percentage of Large vehicles might obstruct the electromagnetic wave propagation (which decrease the average LOS probability).

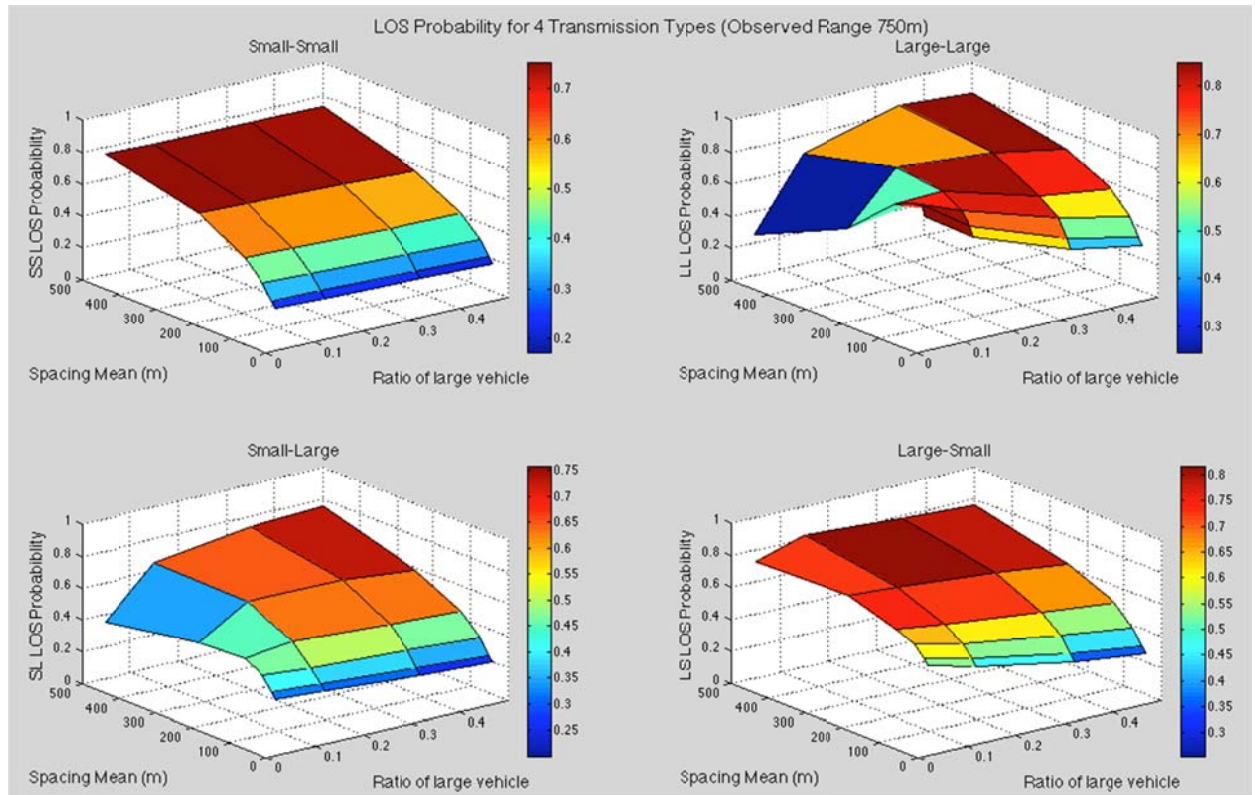


Figure 12. LOS probability for different densities and Large vehicle percentages

3.3.2 Received Power Level

In this set of experiments the received power level measure is investigated. Four types of experiments are performed.

The goal of the first type of experiments is to investigate the received power level experienced when the four different transmission/reception types are used. In this type of experiments the received power level versus the distance from Rx to Tx (within a range of 1000 m) for the 4 transmission/reception types is investigated, see Figure 13. This is accomplished for Scenario 2, shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane, 15% Large vehicles, and the transmission power is set to 63mW.

From this type of experiment it can be concluded that:

1. all the received power level values associated with the Large-Large transmission/reception type are higher than all the received power level values associated with all other transmission/reception types
2. all the received power level values associated with the Small-Small transmission/reception type are lower than all the received power level values associated with all other transmission/reception types
3. all the received power level values associated with the Large-Small transmission/reception type are higher than all the received power level values associated with the Small-Large transmission/reception types
4. for an observed distance equal to 750m:
 - received power level values for Small-Large type are approximately 3dB higher than the values for Small-Small-type
 - received power level values for Large-Small type are approximately 3dB higher than the values for Small-Large-type
 - received power level values for Large-Large type are approximately 3dB higher than the values for Large-Small-type

The goal of the second type of experiments is to investigate the received power level for each transmission/reception type when different vehicle densities are used. In particular, in this type of experiments the received power level versus the distance from Rx to Tx (within a range of 1000 m) for the 4 transmission/reception types is investigated, see Figure 14. This is accomplished for Scenario 2, shown in Table 4, when the vehicle density is set to 17.5 veh/km/lane, instead of 7.9 veh/km/lane, 15% Large vehicles, and the transmission power is set to 63mW.

From this type of experiment it can be concluded that:

1. the received power level conclusions 1, 2 and 3 associated with the first type of experiments described in this section hold also for this type of experiment.
2. for an observed distance equal to 750m, the received power level conclusion 4 associated with the first type of experiments described in this section is similar for this type of experiment. The difference is that now, due to the larger vehicle density, the received power level values associated with the various transmission/reception types, differ between each other approximately 5dB, instead of 3dB.

The goal of the third type of experiments is to investigate the received power level for each transmission/reception type when different Large vehicle percentages are used. In this type of experiments the received power level versus the distance from Rx to Tx (within a range of 1000 m) for the 4 transmission/reception types is investigated, see Figure 15. This is accomplished for Scenario 4,

shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane, 50% Large vehicles, and the transmission power is set to 63mW.

From this type of experiment it can be concluded that:

1. the received power level conclusions 1, 2 and 3 associated with the first type of experiments described in this section hold also for this type of experiment
2. for an observed distance equal to 750m:
 - received power level values for Small-Large type are approximately 3dB higher than the values for Small-Small-type
 - received power level values for Large-Small type are approximately 10dB higher than the values for Small-Large-type
 - received power level values for Large-Large type are approximately 2dB higher than the values for Large-Small-type

When comparing the received power levels for Small-Large and Large-Small transmission/reception types, see Figure 15, it can be seen that if the obstacle is closer located to Tx, then the Small-Large type will have more additional attenuation, thus a lower received power. The fact that the received power difference between the two transmission/reception types becomes larger when increasing the Large vehicle percentage, suggests that obstacles are on the average closer to the sender (Tx).

The goal of the fourth type of experiments is to investigate the received power level for each transmission/reception type when different transmission powers are used. In this type of experiments the received power level versus the distance from Rx to Tx (within a range of 1000 m) for the 4 transmission/reception types is investigated, see Figure 16. This is accomplished for Scenario 2, shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane, 15% Large vehicles, but the transmission power is set to 1996mW (33dBm).

From this type of experiment it can be concluded that:

1. the received power levels for all the 4 transmission/reception types have been improved by approximately 14dB, when using 1996mW (33dBm) transmission power instead of 63mW (18dBm)
2. the received power level conclusions 1, 2 and 3 associated with the first type of experiments described in this section hold also for this type of experiment
3. for an observed distance equal to 750m:
 - received power level values for Small-Large type are approximately 3dB higher than the values for Small-Small-type
 - received power level values for Large-Small type are approximately 3dB higher than the values for Small-Large-type
 - received power level values for Large-Large type are approximately 3dB higher than the values for Large-Small-type

It should be noticed that Figure 16 is using a different limitation for x axis, for the reason that received power level has been improved.

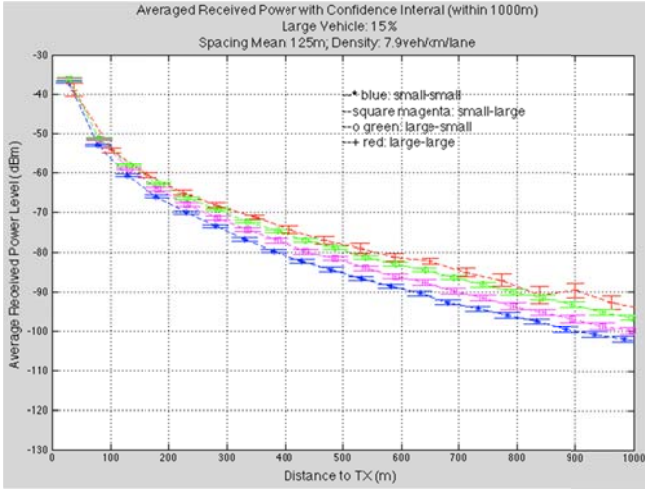


Figure 13. Received power level comparison

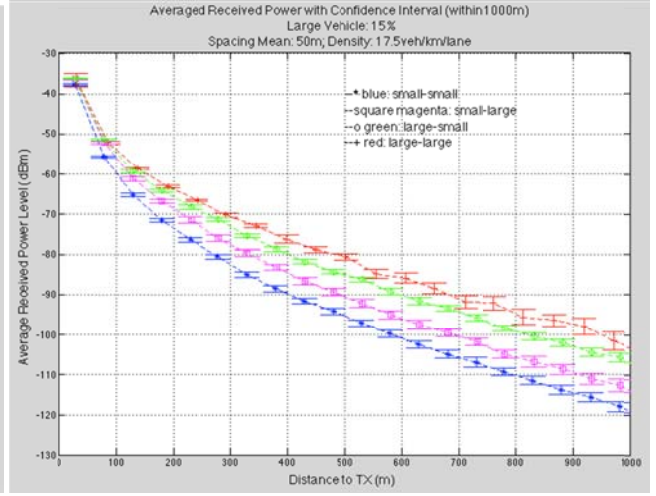


Figure 14. Received power for: 15% Large vehicles and density is 17.5 veh/km/lane (inter-vehicle spacing mean: 50m)

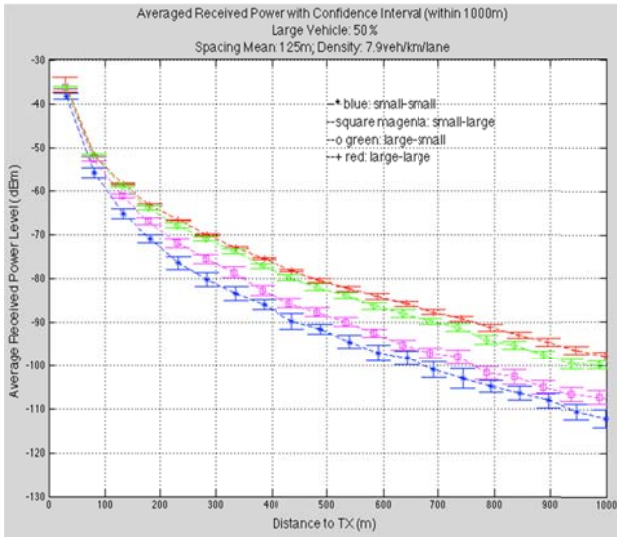


Figure 15. Received power for: 50% Large vehicles and density is 7.9 veh/km/lane (spacing mean: 125m)

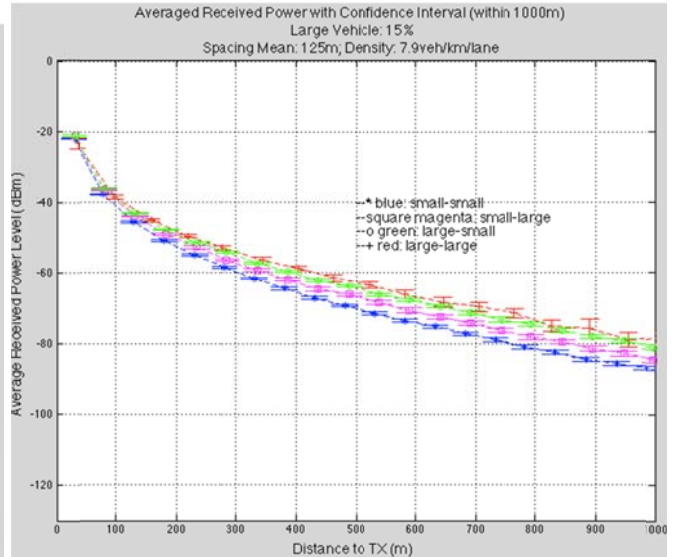


Figure 16. Received power for: 15% Large vehicles, density is 7.9 veh/km/lane and transmission power is 1996mW (33dBm)

Note that the results from other data sets used to compare vehicle densities, Large vehicle percentages and transmission powers in simulation experiments are shown in Appendix A.

3.3.3 Packet Success Rate (PSR)

In this set of experiments the Packet Success Rate (PSR) measure is investigated. Five types of experiments are performed.

The goal of the first type of experiments is to investigate the PSR experienced when different DSRC data rates (i.e., different modulation types and minimum sensitivity thresholds) are used and when different propagation models are applied. The used propagation models for this investigation are the

Free Space Path Loss model, see [WirelessComm.11], and the obstacle-aware propagation model described in Section 2.3.3 of this report. In this type of experiments, see Figure 17, the PSR versus the transmission range for all the communication links in the system is investigated, when varying the DSRC data rates (i.e., 3Mbps, 6Mbps, and 12Mbps). This is accomplished for Scenario 2, shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane and the transmission power is set to 63mW.

From this type of experiment it can be concluded that:

1. for the three investigated DSRC data rates, the PSR values that are measured when the free space model is used are up to 25% higher than the ones that are measured when the obstacle-aware propagation model is used.
2. when the data rate is increasing from 3Mbps to 12Mbps then at 750m, the PSR decreases for the obstacle-aware propagation model from 0.78 to 0.57 and for the free space path loss model the PSR decreases from 1 to 0.78.

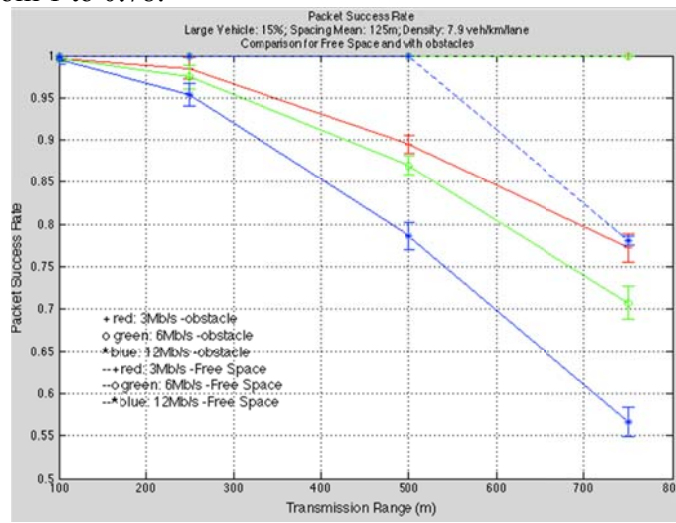


Figure 17. PSR comparison of three DSRC data rates

The goal of the second type of experiments is to investigate the PSR experienced when four different transmission/reception types are used and when the obstacle-aware propagation model is applied. In this type of experiments, see Figure 18, the PSR versus the transmission range for the 4 transmission/reception types is investigated. This is accomplished for Scenario 2, shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane, the data rate is equal to 3Mbps, and the transmission power is set to 63mW.

From this type of experiment it can be concluded that:

1. all the PSR values associated with the Large-Large transmission/reception type are higher than all the PSR values associated with all other transmission/reception types
2. all the PSR values associated with the Small-Small transmission/reception type are lower than all the PSR values associated with all other transmission/reception types
3. all the PSR values associated with the Large-Small transmission/reception type are higher than all the PSR values associated with the Small-Large transmission/reception types
4. for a transmission range equal to 750m:
 - PSR values for Small-Large type are approximately 0.075 higher than the values for Small-Small-type

- PSR values for Large-Small type are approximately 0.05 higher than the values for Small-Large-type
- PSR values for Large-Large type are approximately 0.04 higher than the values for Large-Small-type

The goal of the third type of experiments is to investigate the PSR for each transmission/reception type when different vehicle densities are used. In particular, in this type of experiments the PSR versus the transmission range for the 4 transmission/reception types is investigated, see Figure 19. This is accomplished for Scenario 2, shown in Table 4, when the vehicle density is set to 17.5 veh/km/lane, instead of 7.9 veh/km/lane, 15% Large vehicles, and the transmission power is set to 63mW.

From this type of experiment it can be concluded that:

1. the PSR conclusions 1, 2 and 3 associated with the second type of experiments described in this section hold also for this type of experiment
2. as the vehicle density increases, all the PSR values decrease
3. for a transmission range equal to 750m:
 - PSR values for Small-Large type are approximately 0.08 higher than the values for Small-Small-type.
 - PSR values for Large-Small type are approximately 0.07 higher than the values for Small-Large-type
 - PSR values for Large-Large type are approximately 0.06 higher than the values for Large-Small-type

The goal of the fourth type of experiments is to investigate the PSR for each transmission/reception type when different Large vehicle percentages are used. In this type of experiments the PSR versus the transmission range for the 4 transmission/reception types is investigated, see Figure 20. This is accomplished for Scenario 4, shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane, 50% Large vehicles, and the transmission power is set to 63mW.

From this type of experiment it can be concluded that:

1. the PSR conclusions 1, 2 and 3 associated with the second type of experiments described in this section hold also for this type of experiment.
2. as the Large vehicle percentage increases, all the PSR values decrease
3. for an transmission range equal to 750m:
 - PSR values for Small-Large type are approximately 0.07 higher than the values for Small-Small-type
 - PSR values for Large-Small type are approximately 0.14 higher than the values for Small-Large-type
 - PSR values for Large-Large type are approximately 0.04 higher than the values for Large-Small-type

The goal of the fifth type of experiments is to investigate the PSR for each transmission/reception type when different transmission powers are used. In this type of experiments the PSR versus the transmission range for the 4 transmission/reception types is investigated, see Figure 21. This is accomplished for Scenario 4, shown in Table 4, when the vehicle density is set to 7.9 veh/km/lane, 15% Large vehicles, and the transmission power is set to 1996mW.

From this type of experiment it can be concluded that:

1. the PSR conclusions 1, 2 and 3 associated with the second type of experiments described in this section hold also for this type of experiment.
2. as the transmission power increases, all the PSR values increase
3. for an transmission range equal to 750m:
 - PSR values for Small-Large type are approximately 0.05 higher than the values for Small-Small-type
 - PSR values for Large-Small type are approximately 0.03 higher than the values for Small-Large-type
 - PSR values for Large-Large type are approximately 0.025 higher than the values for Large-Small-type

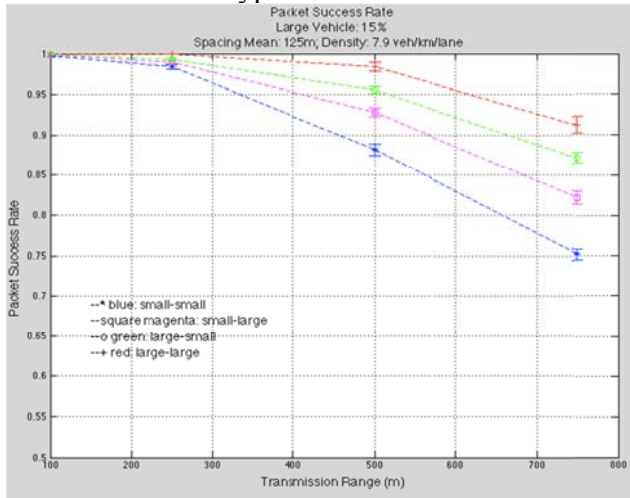


Figure 18. PSR comparison of the 4 transmission types

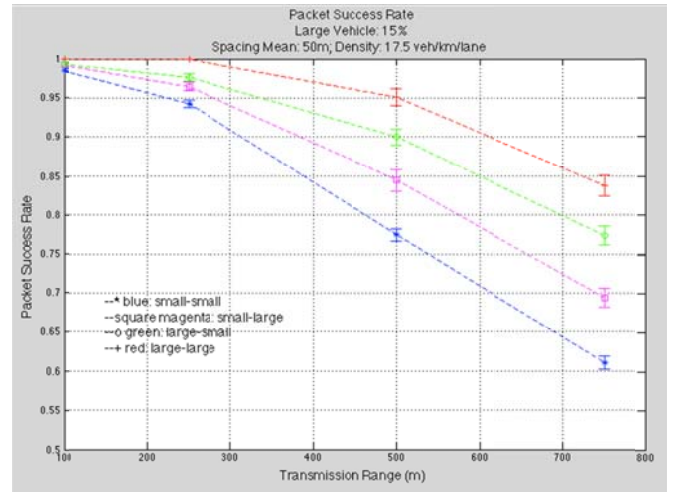


Figure 19. PSR for: 15% Large vehicles and density is 17.5 veh/km/lane (spacing mean: 50m)

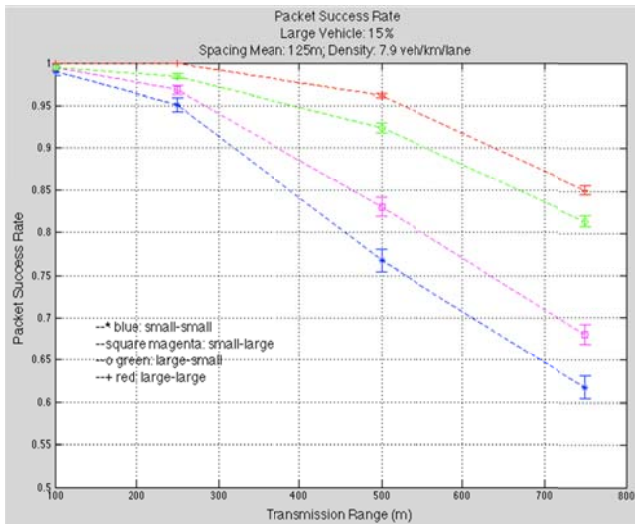


Figure 20. PSR for: 50% Large vehicles and density is 7.9 veh/km/lane (spacing mean: 125m)

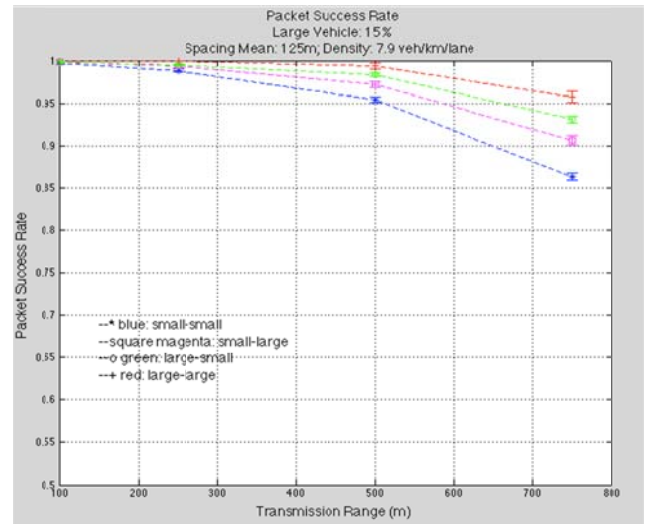


Figure 21. PSR for: 15% Large vehicles, density is 7.9 veh/km/lane and transmission power is 1996mW

Similar conclusions as for the received power level experiments can be derived, when comparing the PSR values for Small-Large and Large-Small transmission/reception types, see Figure 20.

Note that the results from other data sets used to compare vehicle densities, Large vehicle percentages and transmission powers in simulation experiments are shown in Appendix A. The PSR results for these simulation experiments are calculated using the minimum sensitivity threshold of 3Mbit/s.

3.4 Evaluation of the Impact of Large Vehicles When Used as Next Hop

This section answers the second research question, by investigating what is the impact of Large vehicles on multi-hop V2V communication, when these are selected as next hops. Three types of experiments are performed. The used propagation model for the investigation of the Ratio of Large vehicles selected as best next hop, is the obstacle-aware propagation model described in Section 2.3.3 of this report.

In the first type of experiments the Ratio of Large vehicles selected as best next hop is investigated when the percentage of Large vehicles and the data rate are varied. This is accomplished for Scenario 5, shown in Table 5, when (1) the vehicle density is set to 7.9 veh/km/lane (i.e., 125m inter-vehicle spacing mean), (2) the percentage of the Large vehicles on the road is varied from 5% to 50%, (3) the DSRC data rates are varied from 3Mbps to 27Mbps and (4) the transmission power is fixed at 10dBm.

The Ratio of Large vehicles selected as best next hop results are shown in Figure 22. The lower surface shown in Figure 22, represents a reference plane, where the value of the Ratio of Large vehicles selected as best next hop measure for each used sensitivity value is equal to the actual ratio of Large vehicles. The upper surface represents the results of our simulation experiments. Note that Large vehicles consistently provide a larger number of new (second hop) neighbors to the vehicle in question, across different Large vehicle ratios and minimum sensitivity thresholds (i.e., DSRC data rates). We can see that for a constant ratio of Large vehicles, the Large vehicles are more beneficial to be selected as best next hop to relay packets for lower minimum sensitivity thresholds. The minimum sensitivity threshold of -95 dBm exhibited the highest rate of Large vehicles that are selected as best next hop to relay packets.

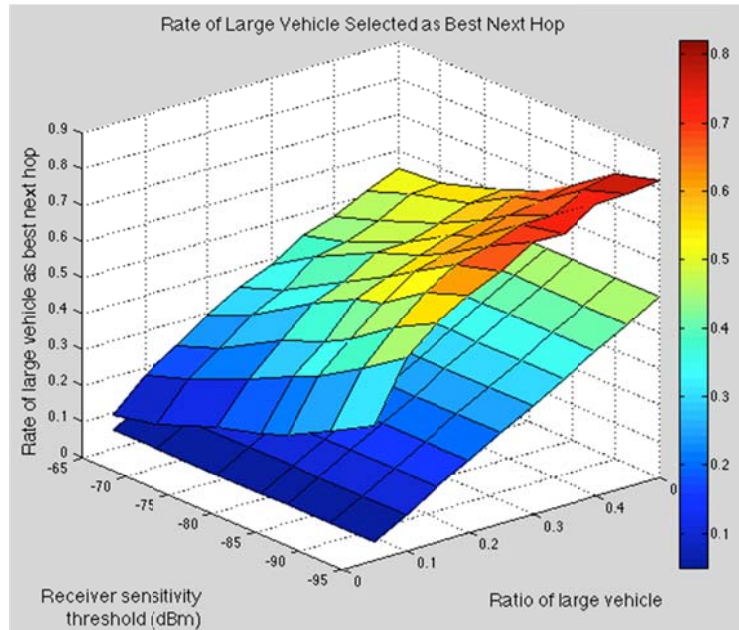


Figure 22. Rate of Large vehicles selected as best next hop, transmission power: 10mW

The conclusions on the Ratio of Large vehicles selected as best next hop that are derived by the simulation results depicted in Figure 22, are similar to the ones derived in [BoMe11]. However, slight differences can be observed. For example, in [BoMe11] is showed that when 15% Large vehicles on the road are used, then across all sensitivity thresholds Large vehicles are selected as best next hop between 30%~45% of the time. In our simulation experiments and for the same parameter values, Large vehicles are selected as best next hop between 25%~60% of the time, see Figure 22.

Furthermore, the statistical accuracy of the results presented in [BoMe11] is much lower than the results that we show in Figure 22, since the calculated confidence intervals for all the performed experiments presented in this report are lower than the $\pm 5\%$ of the shown calculated mean values.

In the second type of experiments the Ratio of Large vehicles selected as best next hop is investigated when the percentage of Large vehicles and the data rate are varied. This is accomplished for Scenario 5, shown in Table 5, when (1) the vehicle density is set to 11 veh/km/lane (i.e., 75m inter-vehicle spacing mean), (2) the percentage of the Large vehicles on the road is varied from 5% to 50%, (3) the DSRC data rates are varied from 3Mbps to 27Mbps and (4) the transmission power is fixed at 10dBm (10dBm).

The results for this type of experiments are shown in Figure 23. The lower surface represents the same reference plane as in Figure 22. The upper surface represents the results of our simulation experiments. Note that Large vehicles still consistently provide a larger number of new (second hop) neighbors to the vehicle in question, across different Large vehicle ratios and minimum sensitivity thresholds (i.e., DSRC data rates). Besides, the minimum sensitivity threshold of -95dBm still exhibited the highest rate of Large vehicles that are selected as best next hop to relay packets. However, the highest rate values in figure 23 are about 0.08 larger than the ones in figure 22. We can conclude that, when increasing vehicle density from 7.9 veh/km/lane to 11 veh/km/lane, Large vehicles are more likely to be selected as best next hop to relay packets, and more benefits can be seen for lower sensitivity thresholds. When 15% Large vehicles on the road are used, now in figure 23 across all sensitivity thresholds Large vehicles are selected as best next hop between 30%~70% of the time.

In the third type of experiments the Ratio of Large vehicles selected as best next hop is investigated when the percentage of Large vehicles and the data rate are varied. This is accomplished for Scenario 5, shown in Table 5, when (1) the vehicle density is set to 7.9 veh/km/lane (i.e., 125m inter-vehicle spacing mean), (2) the percentage of the Large vehicles on the road is varied from 5% to 50%, (3) the DSRC data rates are varied from 3Mbps to 27Mbps and (4) the transmission power is fixed at 18dBm (63mW).

The results for this type of experiments are shown in Figure 24. The lower surface represents the same reference plane as in Figure 22. The upper surface represents the results of our simulation experiments. Note that Large vehicles still consistently provide a larger number of new (second hop) neighbors to the vehicle in question, across different Large vehicle ratios and minimum sensitivity thresholds (i.e., DSRC data rates). Besides, the minimum sensitivity threshold of -95dBm still exhibited the highest rate of Large vehicles that are selected as best next hop to relay packets. However, the highest rate values in figure 24 are slightly larger than the ones in figure 22. Across the minimum sensitivity threshold -70dBm to -85dBm, the rate values in figure 24 are about 0.1 larger than the ones in figure 22. We can conclude from the two figures that, when increasing transmission power from 10dBm to 63dBm, Large vehicles are more likely to be selected as best next hop to relay packets, and more benefits can be seen for lower sensitivity thresholds. When 15% Large vehicles on the road are used, now in figure 23 across all sensitivity thresholds Large vehicles are selected as best next hop between 30%~65% of the time.

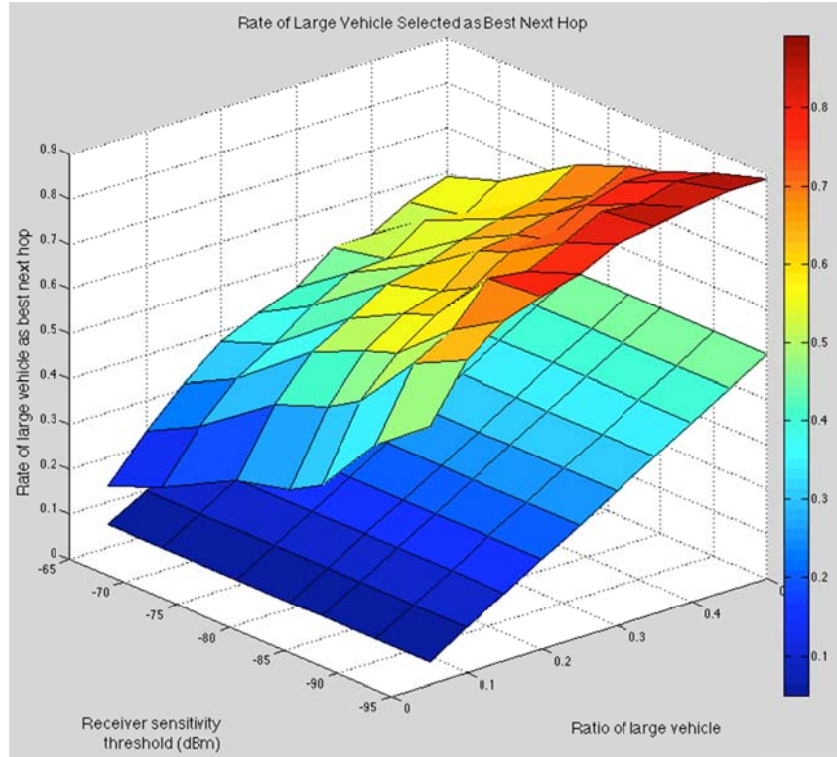


Figure 23. Rate of Large vehicles selected as best next hop, transmission power: 10mW, vehicle density: 11 veh/km/lane (spacing mean: 75m)

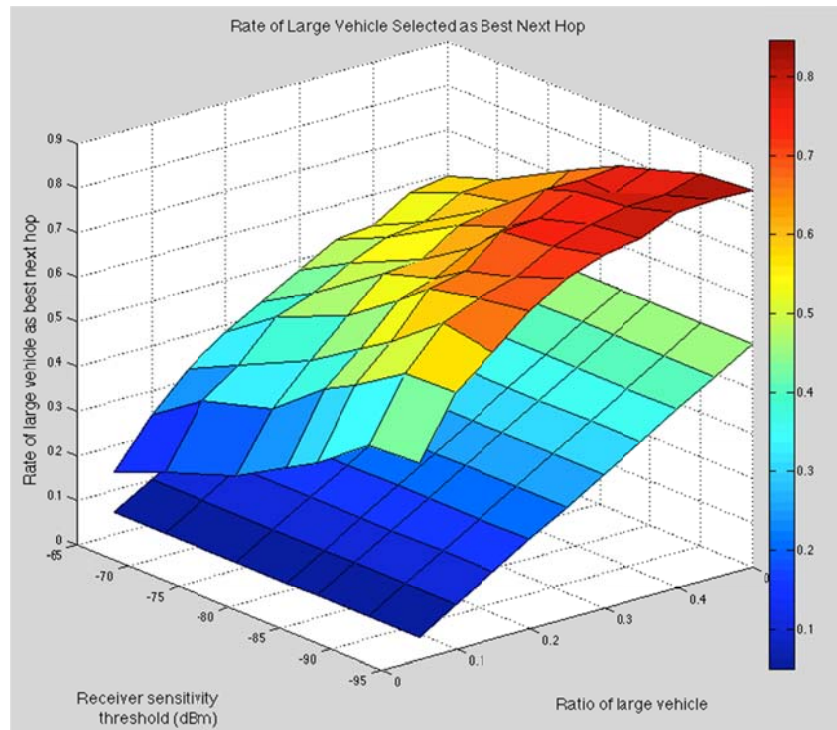


Figure 24. Rate of Large vehicles selected as best next hop, transmission power: 63mW, vehicle density: 7.9 veh/km/lane (spacing mean: 125m)

3.5 Conclusion

In this chapter, the experiments regarded to the two research question in this assignment are performed to 1) evaluate the impact of Large vehicles used as transmitter, receiver or obstacles, when varying vehicle density, Large vehicle percentage and transmission power; 2) evaluate the impact of Large vehicles used as next hop to relay packets.

We can conclude that for the first research question, either increasing vehicle density (decrease inter-vehicle spacing), or increasing percentage of Large vehicles, or decreasing transmission power, can cause a decrease in the results of average LOS probability, received power level and packet success rate. Almost all cases in the simulation experiments suggest that 1) Large-Large transmission/reception type performs consistently and significantly better than other transmission/reception types, 2) Small-Small transmission/reception type performs the worst among the 4 transmission/reception types, 3) Large-Small transmission/reception type performs better than Small-Large transmission/reception type, as the obstacles are located closer to the sender. Besides, for the second research question, as we can see from results in Section 3.4, Large vehicles always have a higher rate of selected as best next hops to relay packets. The minimum sensitivity threshold of -95dBm always exhibited the highest rate of Large vehicles that are selected as best next hop to relay packets. Either increasing vehicle density (decrease inter-vehicle spacing), or increasing transmission power, can lead to a slightly increase in the rate values of Large vehicles selected as best next hop to relay packets, and more benefits can be observed for lower sensitivity thresholds.

4. Conclusion and Future Work

4.1 Conclusions

In this article we have presented an extended evaluation of the impact of Large vehicles on V2V communication, based on the model presented in [BoVi11]. In particular, this report extends the research work presented in [BoVi11], [BoMe11], with extensive simulation studies in which (i) the effect of Large vehicles on V2V communication and (ii) the benefit of choosing a Large vehicle as a next hop are investigated when different vehicle densities, percentages of Large vehicles, transmission power, DSRC data rates (i.e., modulation types and minimum sensitivity threshold) are used.

Based on our results, we conclude that for realistic situations (i.e., inter-vehicle spacing mean smaller than 250m, Large vehicles percentage larger than 5%) the communication links that are using Large vehicles as transmitter and/or receiver perform consistently and significantly better than the communication links that use Small vehicles, from the point of average LOS probability, received power level and packet success rate. Either increasing vehicle density or increasing the percentage of Large vehicles could cause a decrease in the average values of these performance metrics. However, the differences between the performance metrics associated with each the four transmission/reception types (Small-Small, Small-Large, Large-Small and Large-Large) become larger. The simulation experiments on the Ratio of Large vehicles selected as best next hop show that under most situations, Large vehicles are significantly better relay candidates than Small vehicles. The lower the minimum sensitivity threshold, the higher the rate of Large vehicles selected as best next hop to relay packets. Either increasing vehicle density (decrease inter-vehicle spacing), or increasing transmission power, can lead to an increase in the rate values of Large vehicles selected as best next hop to relay packets, and more benefits can be observed for lower sensitivity thresholds.

4.2 Future Work

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

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Appendix A: Additional Experiments Results

Note that the results of the additional experiments in this appendix do not compare the performance behavior when using the 4 transmission/reception types. The data sets associated with all types of communication links are however, considered.

1. Average LOS Probability

Figure 25 shows the comparison for six vehicle densities when Large vehicle percentage is 15%, given in Scenario 2 in Table 4. Figure 26 indicates the comparison for four Large vehicle percentages when vehicle density is 7.9 veh/km/lane (inter-vehicle spacing mean is 125m).

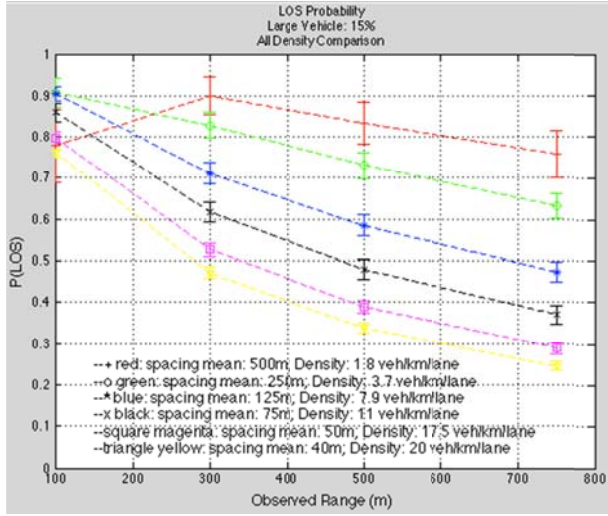


Figure 25. LOS probability for six vehicle densities

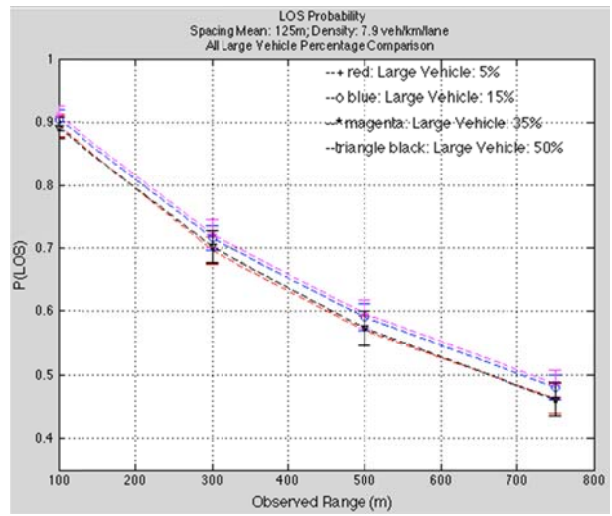


Figure 26. LOS probability for four Large vehicle percentages

2. Received Power Level

Figure 27 shows the comparison for six vehicle densities when Large vehicle percentage is 15%, given in Scenario 2 in Table 4. Figure 28 indicates the comparison for four Large vehicle percentages when vehicle density is 7.9 veh/km/lane (inter-vehicle spacing mean is 125m). Figure 29 gives the comparison for four different transmission powers: 10mW (10dBm), 63mW (18dBm), 316mW (25dBm), 1996mW (33dBm), when Large vehicle percentage is 15% and vehicle density is 7.9 veh/km/lane.

3. Packet Success Rate (PSR)

Figure 30 shows the comparison for six vehicle densities when Large vehicle percentage is 15%, given in Scenario 2 in Table 4. Figure 31 indicates the comparison for four Large vehicle percentages when vehicle density is 7.9 veh/km/lane (inter-vehicle spacing mean is 125m). Figure 32 gives the comparison for four different transmission powers: 10mW (10dBm), 63mW (18dBm), 316mW (25dBm), 1996mW (33dBm), when Large vehicle percentage is 15% and vehicle density is 7.9 veh/km/lane.

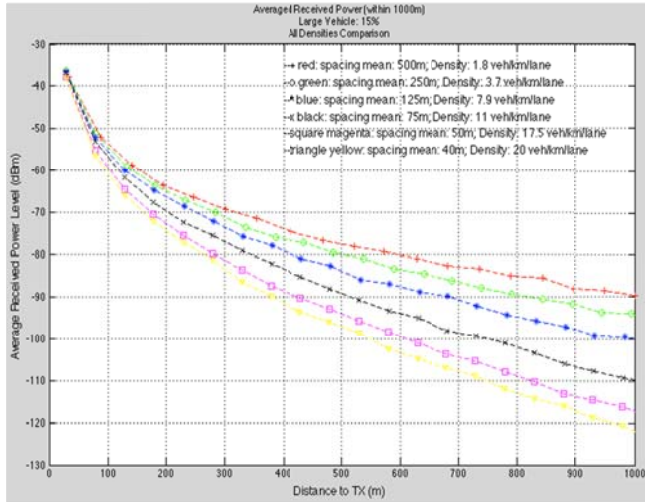


Figure 27. Received power for six vehicle densities

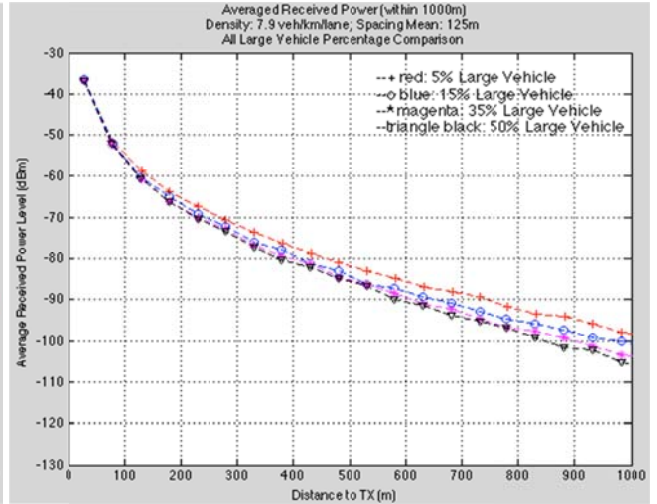


Figure 28. Received power for four Large vehicle percentages

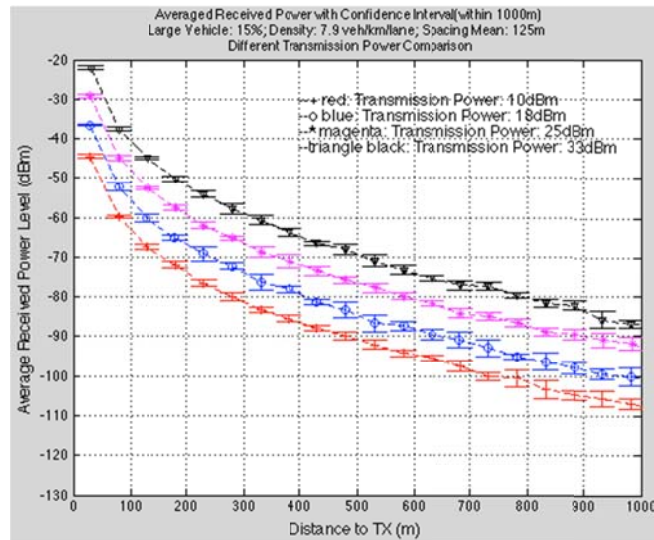


Figure 29. Received power for four transmission powers

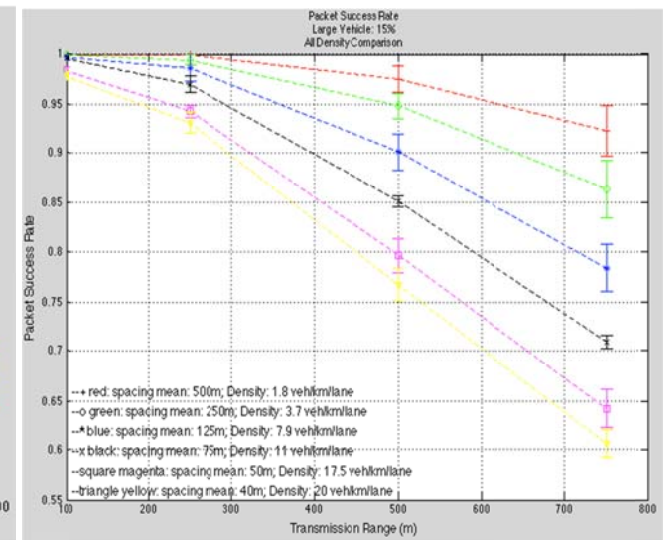


Figure 30. PSR for six vehicle densities

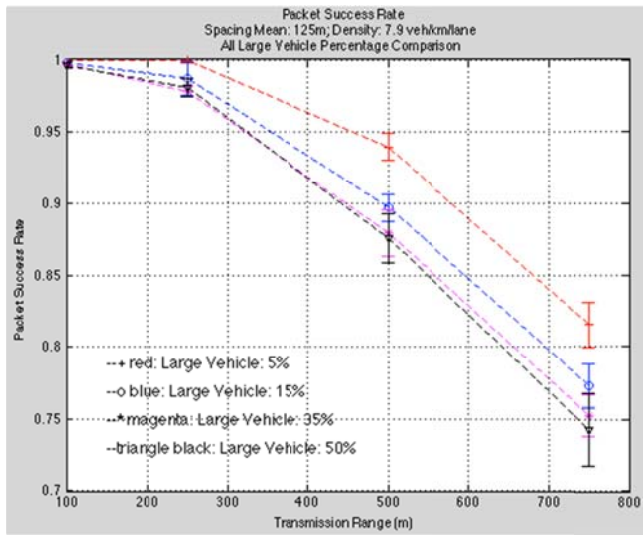


Figure 31. PSR for four Large vehicle percentage

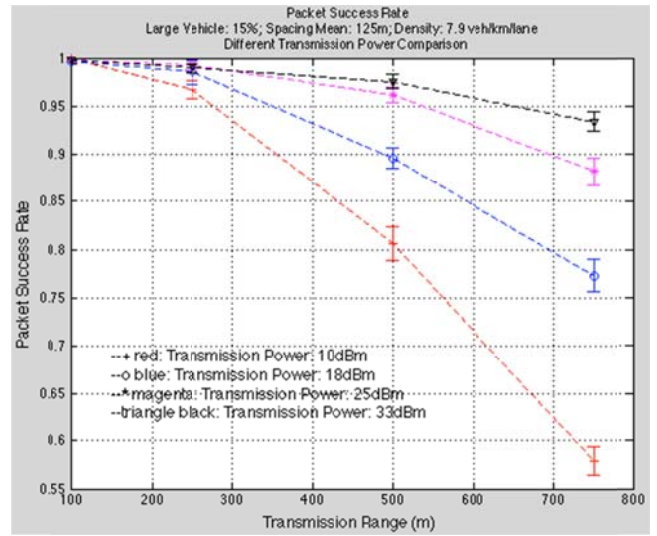


Figure 32. PSR for four transmission power