# Performance Evaluation of V2V Propagation Channels Under Different Link Types

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***Abstract*—Accurate and realistic propagation channel is of paramount requirement in the design of vehicle-to-vehicle (V2V) communications which cover the realistic channel properties and characteristics. Obstructions and propagation link types give significant impact on the communication link and are often ignored in the modelling and analysis of the V2V design and simulation. In this paper, we demonstrate an overview of V2V propagation channel model and wireless channel requirements based on the different link types and obstruction types. We investigate three different environments such as urban, suburban and highway which are in the state of Malacca. We analyze the neighborhood size (defined as the number of vehicles that can communicate with the ego vehicle), received signal power and traffic density under the different environment and link types. The numerical results show that the performance of the V2V communications is directly affected by the link types and the environments. The link quality deterioration is more severe due to the buildings than that due to the vehicles. Majority of the link types are still considered to be line-of-sight (LOS) and this is a promising sign for higher throughput and reliable V2V communication links. This analysis provides insightful planning and modelling foundation in V2V networks.**

***Keywords- geometry-based V2V; propagation channel; link types; vehicle obstruction***

## I. INTRODUCTION

Propagation channel modeling is a well-established area of study, and many methods have been presented in the literature by researchers. The work on the modeling of vehicular channels can be divided into three classes. An analytical method models the characteristics of a radio propagation using statistical methods such as equalization and channel estimation. The application of stochastic models in large scale system-level simulations due to its low computation complexity. Yet, the limitations of the analytical approach are due to modelling the channel characteristics of the specific environment inaccurately methods such as 3D ray-tracing which is used in deterministic or empirical models to compute the propagation characteristics of a given area. At the cost of higher computational complexity, the environment-specific channel modeling methods achieve greater precision.

The geometry-based channel modeling has the capability of illustrating the propagation environment accurately compare with the analytical approach modeling. However, these modeling methods are relying on the information variety regarding the vehicle's surroundings. Such information contains construction geometry data collected from both commercial and publicly accessible sources [1]. Satellite images have also previously been used to accurately model the vehicle-to-vehicle (V2V) channel environment [2]. In order to perform channel characterization on a city-wide scale, the environment-specific channel modeling techniques uses realistic vehicular mobility traces.

In literature, several propagation models considered different obstruction types such as foliage, vehicles, and buildings. In [2], the authors proposed a propagation model to differentiate the line-of-sight (LOS) and non line-of-sight (NLOS) link types by using location information regarding the road topology. The authors of [3] used satellite based images to reconstruct the information of 3D building geometry. The signal strength at the constructed 3D terrain is determined by applying ray-tracing. In [4], the authors investigated the impacts of an obstruction vehicle affecting signal propagation under time of the day, LOS conditions, and several environments. The measurements are conducted utilizing custom-built vehicle networking hardware. The authors of [5] provide a measurement-based analysis in order to quantify the impact of several propagation on the communication of vehicular in various urban environments with several terrain traffic flow and elevation variations. In [1], the authors designed an efficient propagation model for vehicle-to-vehicle communication named geometry-based V2V propagation model (GEMV2). The model simulates the radio propagation of a city-wide networks with thousands of vehicles on commodity hardware. In [6], the authors utilize the propagation model proposed in [1] to simulate the V2V communication for a chosen area in Doha, Qatar. In [7], the authors investigated various tests to study impacts of the vehicles obstruction in terms of both the throughput and packet error rate (PER). The authors have studied further the impacts of increasing the power of transmission and distance

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of V2V communication on the PER. The authors of [8] analyzed the impacts of the massive vehicle positions and separation distance on several mechanisms of signal propagation. Based on [8], a significant increase in signal attenuation is reported.

V2V communication networks become reality with the release of the first standardization package by ETSI and CEN/ISO following the EC mandate/453 [9]. V2V communications enable a number of applications capable of making the modern-day transportation more enjoyable, more effective and safer. Nonetheless, the reliable and efficient design of V2V systems demands a better knowledge and understanding of the surrounding environment. Currently, characteristics of the vehicle-to-vehicle propagation significantly vary on the large and small scale areas. This variation is due to the dynamic nature road mobility and the vehicular traffic geometry. Based on [1], results and measurements conclude that the vehicular-to-vehicular propagation and communication are impacted by both mobile objects such as mobile cars and trucks, and static objects such as foliage, trees and surrounding buildings.

In [10], four varying frequency bands of V2V channel are measured in highway and urban scenarios. The study is performed to investigate the effect of vehicle blockage size upon the power received and other signal parameters. The channel measurement has taken place at two locations, Germany and China. It is concluded that vehicle blockage does not hinder high frequency V2V communication link. In another study, a shadow fading model is introduced into V2V simulation [11]. Real data is used in this work, and the implemented simulation scenarios are highway and urban. The observed data showed that additional loss is produced when LOS is blocked by vehicle. The proposed model is assimilated into a vehicular ad hoc network (VANET) simulator and compared with Nakagami-m channel model. In addition to that, another research to analyze shadowing problem in highway is published in 2017 [12]. Multilink shadowing effects is highlighted by the authors and implemented in situation of a vehicle taking emergency brake. LOS and obstructed LOS by vehicle propagation type is emphasized, whereas NLOS due to buildings is not available in the simulation scenario. The authors analyzed the highlighted problem and built a new shadowing model that can be incorporated as input to VANET simulators.

All the previous works lack comprehensive visualization of V2V network performance in different environments like urban, suburban and highway which have different channels and features. In this paper which is also the extension of our previous work in [13], our main aim is twofold: firstly, we demonstrate an overview of V2V propagation channel model and wireless channel requirements based on the different link types and obstruction types; secondly, we investigate three different environments such as urban, suburban and highway which are located in the state of Malacca. We analyze the neighborhood size (defined as the number of vehicles that can communicate with the ego vehicle), received signal power and traffic density under the different environment and link types. We show the impact of obstructions due to buildings and vehicles under different environments and analyze the LOS and NLOS links in these environments. This analysis provides insightful planning and modelling foundation in V2V networks. In this paper, we use a geometric based propagation model (GEMV2) to simulate the vehicular-to-vehicular communication in the city.

The rest of this paper is organized as follows. Section II demonstrates the simulation methodology. Section III provides the numerical results of the paper. Finally, Section IV concludes this paper.

## II. SIMULATION METHODOLOGY AND SETUP

Based on Fig. 1, four main steps are required to conduct and visualize the geometry-based V2V communication simulation.

### A. Simulation Workflow

Flowchart below describes the overall workflow proposed in this study. Two simulation software, Simulation Urban Mobility (SUMO) and Geometry-based Efficient propagation Model for V2V communication (GEMV2) are the key components in the workflow. Fig. 1 illustrates the workflow of the simulation model

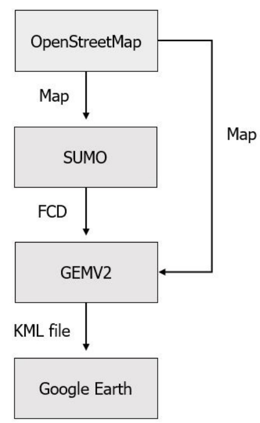

Fig. 1: Simulation workflow

Firstly, the chosen simulation area is exported into map.osm file from OpenStreetMap (OSM) website. The downloaded map is the input for both SUMO and GEMV2 applications. From SUMO, a vehicular mobility trace file or also known as Floating Car Data (FCD) is extracted. Then, the vehicular mobility trace file with the map are loaded into GEMV2. GEMV2 stores the output after simulation execution in two files, comma-separated values (CSV) files that contain the data figure and Keyhole Markup Language (KML) files, which can be visualized in Google Earth.

### B. Simulation Urban Mobility (SUMO)

Simulation Urban Mobility (SUMO) software has been developed since 2000 by the Institute of Transportation Research (IVF) of German Aerospace Centre (DLR) [14]. The functionality of the software has been improved over the time, and many versions are released until the latest version 1.8.0, which is used in this study. SUMO package can be downloaded directly from the website. Inside the package, the user is provided with all necessary tools and library for the traffic simulation. In addition to SUMO installation, the user also required to install Phyton 2.7 separately, as many of SUMO tools are using Phyton programming language [15]-[17].

### C. *Geometry-based Efficient propagation Model for V2V communication (GEMV2)*

Like SUMO, Geometry-based Efficient propagation Model for V2V communication (GEMV2) software also comes in package and can be downloaded from the developer website. GEMV2 run on MATLAB, therefore the installation of MATLAB software is required. GEMV2 is composed of many MATLAB scripts that contain different functions of GEMV2. Among these files, four files deliver the main functions in GEMV2. Those are simSettings.m, runSimulation.m, simMain.m, and simOneTimestep.m. We use the default maximum communication range available in GEMV2 and each link type has the maximum range as shown in Table I.

TABLE I. DEFAULT MAXIMUM COMMUNICATION RANGE IN GEMV2

| Propagation link type | Maximum communication range (m) |
|---|---|
| LOS | 500 |
| NLOSv | 400 |
| NLOSb | 300 |

### D. *Environment*

The environment in V2V communication can be categorized into urban, suburban, highway and rural [18]. All environments are included in this study, except rural area. However, the definition of urban and suburban may vary depending on region or country.

- Urban: Scenario with high traffic density. The buildings or houses in this scenario usually very close to the road.
- Suburban: Suburban scenario has lower traffic density than in urban. The houses and buildings are located a bit far from the road. It also has more open spaces than urban.
- Highway: Open spaces environment, and the vehicles in this scenario move at a high speed. The surrounding of this environment usually trees, or several houses that located far from main road.

## III. NUMERICAL ANALYSIS

In this chapter, the data from the simulation output are tabulated into table and graphs. The simulation output data are analysed according to three parameters; propagation link type, received signal power and traffic density. The propagation link type can be classified into line-of-sight (LOS), non-LOS due to buildings (NLOSb) and non-LOS due to vehicles (NLOSv). Each scenario should have a different distribution of propagation link type due to its distinctive environment features. The power variation of the received signal is also provided for each scenario. For the traffic density parameter, it is evaluated in terms of number of neighbouring vehicles and communication pairs generated.

### A. *Propagation Link Type*

In Fig. 2, specific propagation link type (LOS, NLOSb, NLOSv) from different scenarios are grouped together for comparison. It is obvious that majority of the vehicle pairs in all scenarios are able to communicate directly within their line of sight. The communicating vehicles are likely to be affected by obstructing vehicles rather than buildings. This is reasonable, because the buildings are static beside the road and will not interfere with the moving vehicles that may appear in between of two communicating vehicles.

As expected, NLOSb propagation is typically common in urban rather in suburban scenario. This is due to higher density of buildings and its location are closer to the road in urban scenario. While in the highway scenario, there is no NLOSb propagation link generated because the chosen location is an open space location without building and surrounded with trees only. In real situation, the traffic of the urban area is expected to be very congested and slow, due to high number of vehicles on road and lots of traffic light. Although the area of extracted urban map was similar to the suburban, the route inside the urban map is widely dispersed compared to the suburban map. When small number of generated vehicles distributed throughout the spreading route, the vehicles were less likely to encounter other obstructing vehicles such as truck. In addition, the congestion factor, which mainly the cause of NLOSv propagation also reduced. Therefore, less number of NLOSv communicating pairs generated in the urban scenario.

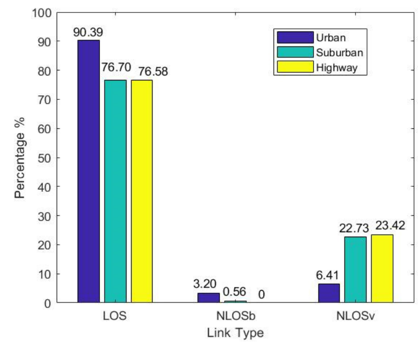


Fig. 2: Percentage of propagation link types in urban, suburban and highway scenarios

### B. *Received Signal Power*

The received signal power according to propagation link type for each scenario is presented in Table II. The maximum received signal power can be reached in this simulation is -32.643 dBm, while the minimum is -97.686 dBm. Communication pairs with LOS signal are able to receive the highest signal power, with signal attenuation from the transmitting to receiving vehicles around -12 dBm to -16 dBm. The performance of NLOSv received signal is the average with the highest power of -40.763 dBm achieved in suburban scenario. The signal attenuation in NLOSv is varying from -20 dBm to -32 dBm, which is doubled from the attenuation range in LOS signal. NLOSb signal has the worst performance as it is only able to achieve maximum received power of -68.835 dBm in urban scenario, and deteriorated to -84.730 dBm in suburban scenario. However, the data shown that LOS signal also degrades on par with the lowest received power of NLOSv. This might be due to the default of maximum communication range in GEMV2 are 500 m, 400 m and 300 m for LOS, NLOSv and NLOSb respectively. Hence, it can be assumed that the distance between the particular LOS communication pair is close to the maximum distance, which is 500 m. Although there is no solid data to be presented regarding the exact distance between the communicating vehicles, it is theoretically known that the signal attenuation worsens along with the increased distance between transmitter and receiver.

TABLE II. SUMMARY OF THE RECEIVED SIGNAL POWER ACCORDING TO PROPAGATION LINK TYPE

| Link Type | Simulation Scenario / Power Received (dBm) | Urban | Suburban | Highway |
|---|---|---|---|---|
| LOS | Average | -75.635 | -74.553 | -71.583 |
| | Highest | -32.643 | -33.459 | -35.801 |
| | Lowest | -86.283 | -86.193 | -85.900 |
| NLOSb | Average | -93.466 | -95.288 | - |
| | Highest | -68.835 | -84.730 | |
| | Lowest | -97.686 | -97.666 | |
| NLOSv | Average | -75.555 | -73.318 | -76.173 |
| | Highest | -44.46 | -40.763 | -51.508 |
| | Lowest | -87.764 | -87.890 | -87.891 |

Fig. 3 illustrates the cumulative distribution function (CDF) of the received signal power for urban, suburban and highway. There is a huge gap between the distribution power of NLOSb signal with the other signals, as can be seen in urban and suburban scenarios. NLOSb signal is distributed at the average power of -90 dBm in both scenarios. Still, communication pairs have slightly better reception of NLOSb signal in the urban scenario than in suburban due to shorter distance of travelling signal. Meanwhile for LOS and NLOSv signals, the received power distribution patterns are almost consistent in all scenarios. Approximately, only 5% of the communication pairs received higher than -50 dBm in LOS and NLOSv situation, with additional loss of -30 dBm or lower from the transmitting antenna. This is unavoidable in vehicular communication as both transmitting and receiving objects are moving, hence fading and variation in receiving signal is bound to occur. To solve this problem, the Road Side Unit (RSU) can be planted alongside of the road to improve the quality of received signal. RSU is one of the components in vehicular communication and has the resemblance of a base station in the cellular network.

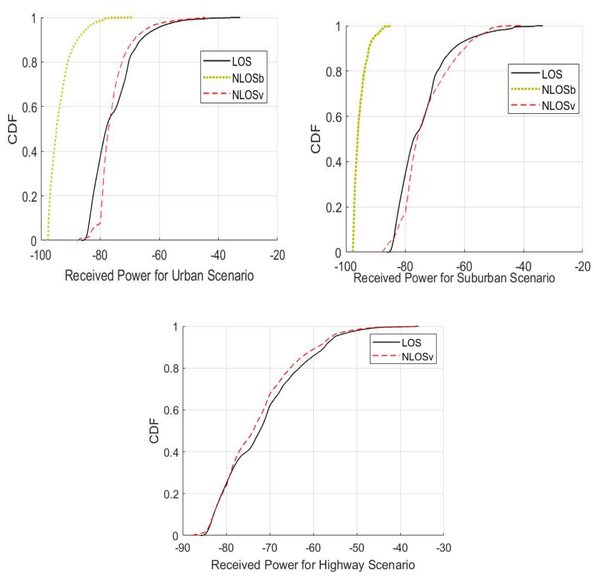


Fig. 3: CDF of received signal power for urban, suburban and highway

## C. Traffic Density

Table III describes the total of communication pairs generated during the simulation according to scenarios. The communication pairs that beyond the maximum range are indicated as 'Inf' or infinity by GEMV2 in the output file and no computation of signal power.

TABLE III. SUMMARY OF COMMUNICATION PAIRS GENERATED IN SIMULATION

| Simulation scenario | Urban | Suburban | Highway |
|---|---|---|---|
| Total of communication pairs generated | 99 093 | 105 853 | 78 049 |
| Total of communication pairs within range (feasible) | 84 028 | 93 314 | 71 811 |
| Communication pairs out of range | 15 065 | 12 539 | 6 238 |

We use the default communication pairs set in GEMV2 to be below 400 throughout the simulation time step. In Fig. 4, there is no communicating pair yet at the beginning of the simulation. The number of vehicles generated is small in the early simulation time and less likely to encounter each other. As the time step increase, the number of communication pairs also gradually increase. Communication pairs number in suburban scenario increase rapidly at earlier time step compared to urban and highway scenarios. Around time step 50s, simulation of suburban scenario starts to reach the peak number of communication pairs, followed by urban scenario. In contrast, the communication pairs in highway scenario only reaching the peak after 150 s. It is apparent that suburban scenario is the fastest to be loaded with communication pairs, while highway scenario is the steadiest in the simulation.

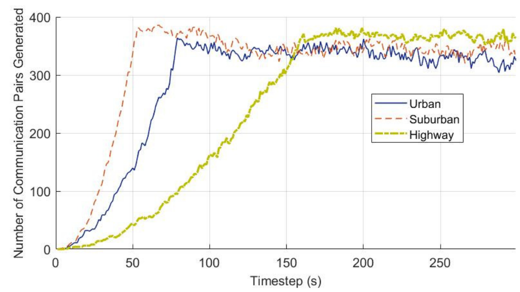


Fig. 4: Number of communication pairs generated per time step in urban, suburban and highway scenarios

In addition to communication pairs, traffic density of a scenario also can be analysed from its neighbouring size. In the simulation, a vehicle may have more than one neighbouring or surrounding vehicles at one time. Thus, GEMV2 will only consider neighbouring vehicles that are within the communication range. Urban scenario has the largest neighbourhood size, with maximum of 27 vehicles at one time. Suburban scenario is the second largest with 24 neighbouring vehicles and followed by highway, 18 neighbouring vehicles. Urban scenario may achieve the highest number of neighbouring vehicles, but it is not the most congested traffic in this simulation. Detailed inspection on Fig. 5 shows that the probability of a vehicle in suburban scenario to have five neighbouring vehicles is higher than in urban scenario, as well as probability for ten neighbouring vehicles. Therefore, suburban scenario is inferred to have the highest traffic density based on the findings of the simulation.

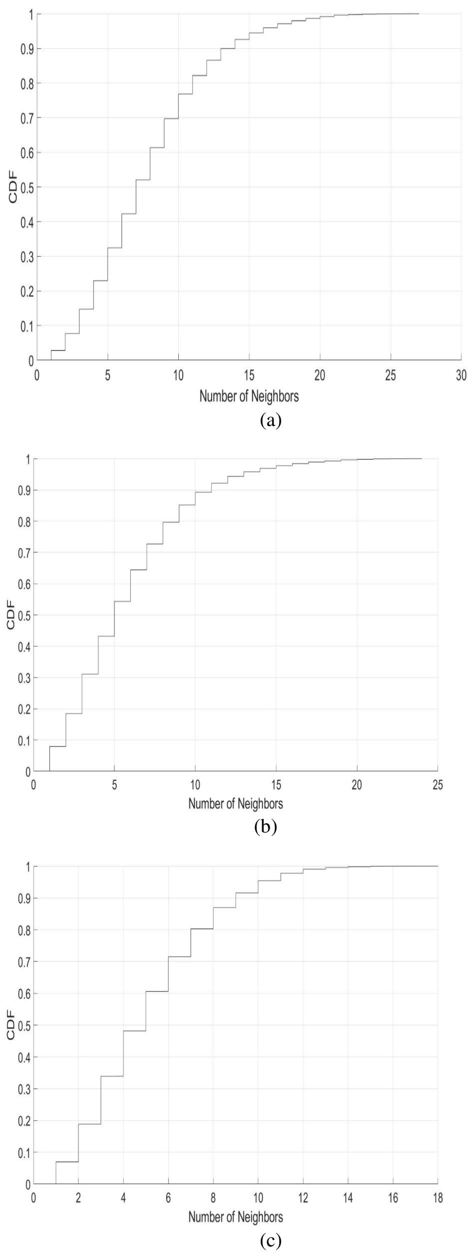


Fig. 5: CDF for number of neighbouring vehicles in (a) urban, (b) suburban and (c) highway

## D. Google Earth Visualization

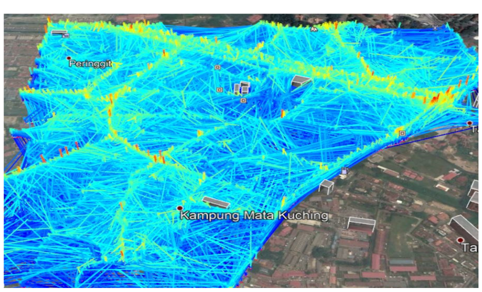


Fig. 6: Received power visualization of urban scenario

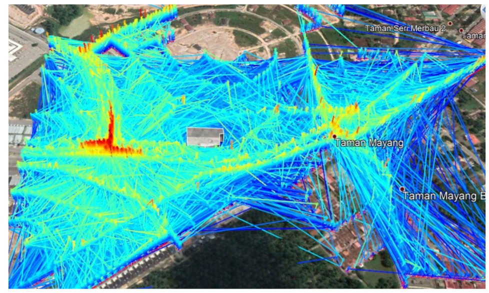


Fig. 7: Received power visualization of suburban scenario

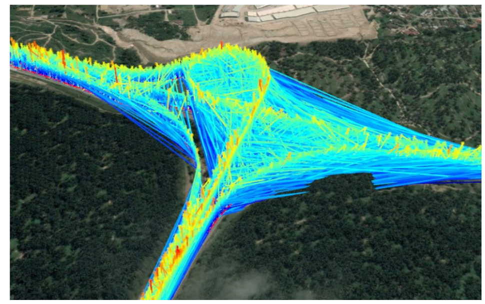

Fig. 8: Received power visualization of highway scenario

Fig. 6, 7 and 8 depict the visualization of received power in urban, suburban and highway scenarios. Three output KML files from GEMV2, consisting of building and vehicle polygons, number of neighbouring vehicles and received power are loaded and visualized in Google Earth.

TABLE IV. SUMMARY OF THE SIMULATION RESULTS UNDER DIFFERENT ENVIRONMENTS AND LINK TYPES

| Scenario | Urban | Suburban | Highway |
|---|---|---|---|
| Total communication pairs within range (feasible) | 84 028 | 93 314 | 71 811 |
| **LOS communication pairs**<br>Power received (dBm):<br>Average<br>Highest<br>Lowest | 75 955 (90.392%)<br><br>-75.635<br>-32.643<br>-86.283 | 71575(76.703%)<br><br>-74.553<br>-33.459<br>-86.193 | 54993 (76.58%)<br><br>-71.583<br>-35.801<br>-85.900 |
| **NLOSb communication pairs**<br>Power received (dBm):<br>Average<br>Highest<br>Lowest | 2686 (3.197%)<br><br>-93.466<br>-68.835<br>-97.686 | 525 (0.563%)<br><br>-95.288<br>-84.730<br>-97.666 | - |
| **NLOSv communication pairs**<br>Power received (dBm):<br>Average<br>Highest<br>Lowest | 5387 (6.411%)<br><br>-75.555<br>-44.460<br>-87.764 | 21214(22.734%)<br><br>-73.318<br>-40.763<br>-87.890 | 16818 (23.42%)<br><br>-76.173<br>-51.508<br>-87.891 |
| Average received power, all link types (dBm) | -76.200 | -74.389 | -72.658 |
| Highest received power (dBm) | -32.643 (LOS) | -33.459 (LOS) | -35.801 (LOS) |
| Lowest received power (dBm) | -97.686 (NLOSb) | -97.666 (NLOSb) | -87.891 (NLOSv) |

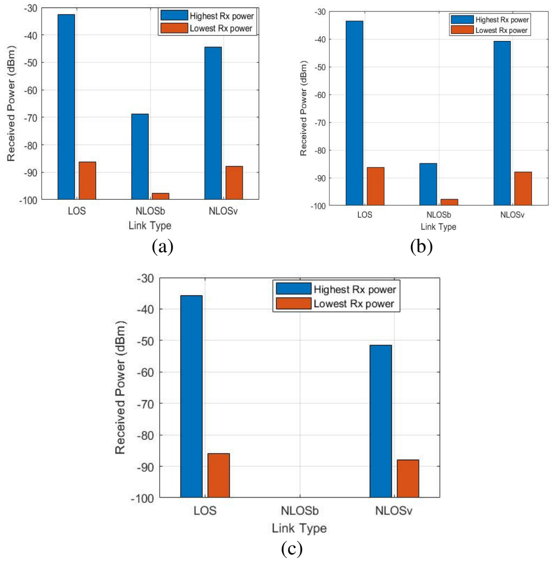


Fig. 9: Min-max received power (in dbm) in (a) urban, (b) suburban and (c) highway

Table IV summarizes the numerical results of our simulation work under different environments and link types. It clearly shows that LOS link is still dominant in all environments and average received signal quality is not quite different in all cases. Fig. 9 illustrates the min-max received power in the environments under different link types. There are three channel propagation types investigated in the simulation, LOS, NLOSv and NLOSb. Each of the propagation type is determined by the signal power received and the power distribution throughout the simulation time. Due to its unobstructed path, LOS link is able to provide maximum power transmission from transmitting vehicle to the receiving vehicle. However, there is no NLOSb link generated in highway scenario. This finding agrees with [22], where highway scenario is usually an open space with no building surrounds the road. In any propagation type, attenuation loss is unavoidable, especially in V2V channel that has the characteristic of time-varying for both transmitter and receiver. This implies that every single detail of channel metrics should be considered in executing V2V communication into real scenario.

## IV. Conclusion

This paper provides a comprehensive visualization of V2V propagation channel model and wireless channel requirements based on the different link types and obstruction types. We also investigate three different environments such as urban, suburban and highway which are in the state of Malacca. We analyze the neighborhood size, received signal power and traffic density under the different environment and link types. We find that the link quality deterioration is more severe due to the buildings than that due to the vehicles. Majority of the link types is still LOS and this is a promising sign for higher throughput and reliable communication links in the environments for V2V networks. This analysis provides insightful planning and modelling foundation in V2V networks. Future works includes employing optimization tools like ant colony optimization to get the optimal number of traffic in each environment for a reliable and efficient V2V networks.

## Acknowledgments

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