Performance Analysis of Radio Propagation Models in VANET Application

Nurain Izzati Shuhaimi[1], Nur Liyana Ashmadi[2], Ezmin Abdullah[3], Roslina Mohamad[4] and Sarah Yasmin Mohamad[5]
[1,2,3,4]Faculty of Electrical Engineering, Universiti Teknologi MARA Shah Alam, 40450 Shah Alam, Selangor, MALAYSIA.
[5]Department of Electrical and Computer Engineering Kulliyyah of Engineering International Islamic University Malaysia, MALAYSIA.
nurainizzati@uitm.edu.my

***Abstract*—Vehicular Ad-hoc Network (VANET) is developed for the communication between vehicle-to-vehicle and vehicle-to-roadside in purpose for safety, navigation and other roadside services. The radio propagation model (RPM) was used in VANET for the implementation of VANET in order to estimate the path loss in multiple operating environments such as modern road infrastructure. This research is concerned with the study about the performance of different RPM on VANET between Free Space propagation, Two Ray Ground propagation and Nakagami propagation. The purpose of this research work is to observe the packet loss, throughput and average end-to-end delay between vehicles by implementing different type of RPMs, which then has been compared to determine which RPM has a better performance. To obtain the performance analysis of RPM in VANET, several software such as Java OpenStreetMap (JOSM), Simulator of Urban Mobility (SUMO), Mobility Model Generator for VANET (MOVE) and Network Simulator Version 2 (NS2) has been used with Linux Ubuntu version 20.04 as the operating system. The data were collected at Jalan Besar Selayang Baru, 68100 Batu Caves, Selangor. With the target location of 2 km x 2 km size, detail analyzation of data from all three different propagation models were performed. Hence, the best performance of RPM in VANET has been identified.**

Keywords—Vehicular Ad-hoc Network (VANET), Radio Propagation Model (RPM), JOSM, SUMO, MOVE, NS2, Ubuntu 20.04

I. INTRODUCTION

An ad hoc network in general refers to a network link formed between two or more devices without a wireless router or access point used. For any natural disasters, emergency operations, or even a simple connection between two devices, the self-supporting existence of the ad hoc network is very useful. Briefly, the Wireless Ad-hoc Network (WANET) uses radio frequencies instead of physical cables to transmit data between source and receiver as it is a decentralized type of wireless network[1]. WANET is classified into three different categories which each have their own characteristic; Wireless Mesh Network (WMN), Wireless Sensor Network (WSN) and Mobile Ad-hoc Network (MANET)[2, 3]. The organization of Wireless Ad-hoc Network (WANET) is illustrated in Figure 1.

VANET has been implementing the principles of MANET, a method of spontaneous development of mobile wireless network devices that can change locations and customize themselves through wireless network [4]. VANET also is affiliated with the term inter-vehicle communication (IVC), which serves as communication nodes for vehicles and facilities such as roadside units (RSUs) and cellular networks and then communicates with each other [2, 5, 6].

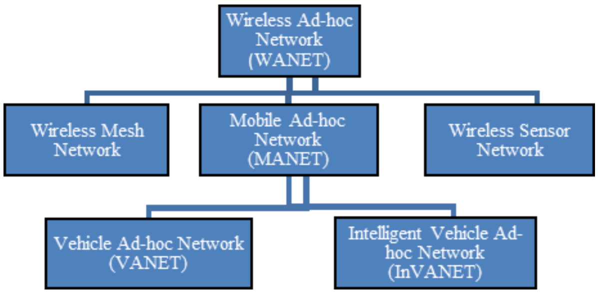

Fig. 1. The classification of WANET [3]

Furthermore, VANET may help ensure easy and efficient communication between vehicles on dynamic mobility combining various ad-hoc networking systems, such as Wi-Fi IEEE 802.11 b/g, WiMAX IEEE 802.16, Bluetooth, IRA, and ZigBee, with an intelligent way of using vehicular connectivity [6-8]. Figure 2 shows the scenario of how VANET works on the road traffic. Vehicle to Infrastructure (V2I), Vehicle to Vehicle (V2V) and the combination of both (V2X) communications are classified as VANET communication [1, 5]. Design and implementation of VANET is very complicated in the continuous growth of the automobile industry and consists of a wide area of research as the application of VANET is quite important and useful for technological innovations today.

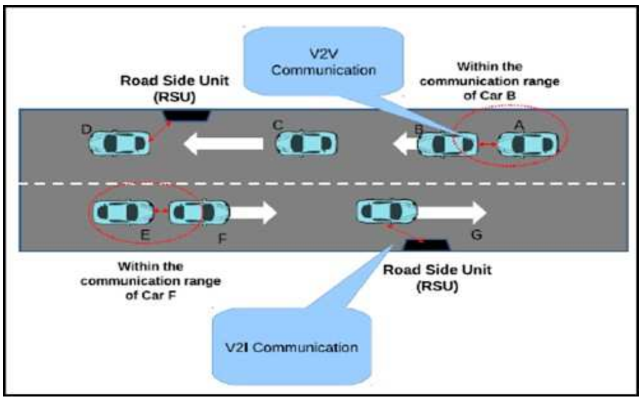

Fig. 2. The scenario of VANET [10]

The scope of this project is focusing on of the important feature in VANET which is RPM. RPM is an empirical mathematical formulation used to explain the propagation of radio waves, such as frequency, distance and other conditions [1, 7]. The analysis of the performance was performed by observing three performance metrics which are the throughput, packet loss and end-to-end delay of data communication between vehicles or RSUs. The rate of efficient transmission of messages over a communication channel is throughput for communication networks like Ethernet or Packet Radio[10, 11]

A radio propagation model is typically built to predict propagation behaviour under similar constraints for all similar connections [12, 13]. In VANET, RPM is used in many operational environments to estimate path loss [13]. Modern road infrastructures such as flyovers, under passes and road tunnels are the working environments [4]. For instance, in order to predict the behaviour of propagation, different RPMs must be created for different environments.

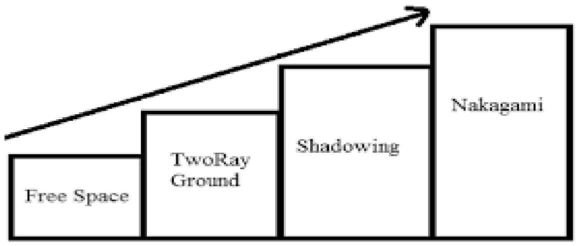

Fig. 3. Radio propagation models evolution for VANET[15]

Figure 3 shows various type of RPM and the evolution of it. Based on the figure shown, only three RPMs were chosen for the evaluation of their performance in VANET which are Free Space model, Two Ray Ground model and Nakagami model. The required frequency ranges for vehicular interaction which was 5 GHz frequency band was used for the field measurement. The results of the investigation could demonstrate the performance analysis of RPM in VANET application. Each radio propagation model performances will be covered in details to determine their suitability on VANE application.

A. Free Space Propagation Model

The earliest radio propagation model which was used in MANET is Free Space Radio Propagation. This model is also often referred to as the Friis model. The radio waves move in free space, away from any other artifacts that could impact them. As shown in Figure 4, The power received depends only on the power transmitted, the gain of the antenna and the distance between the sender and the receiver. The distance from the source is what determines the way of traveling in which the signal intensity decreases. The concept is commonly to decrease the power with the square of the distance when a radio wave moves away from an omni-directional antenna[14].

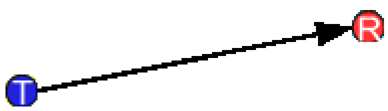

Fig. 4. Free Space propagation model [16]

Based in Equation (1)[14], P(d) is Watt's received signal power. Thus Pt is the signal power transmitted. The gains of the receiving and the transmitting antennas are Gt and Gr, respectively. L is the failure of the device, is the distance between the transmitter and the receiver and the wavelength is λ , lambda.

$$P(d) = \frac{Pt\ Gt\ Gr\ \lambda^2}{(4\pi)^2 d^2\ L} \tag{1}$$

As referred from Equation (1), the signal received depends on the transmitted signal strength, the gains of the antennas receiving and transmitting, as well as the distance between the sender and the recipient. The model of free space basically represents the range of communication as a circle around the transmitter. If a receiver is inside the circle, all packets are received by it. Otherwise, all the packets will be lost.

B. Two Ray Ground Propagation Model

Two Ray Ground is also one of the RPM used for protocols performance in VANET. This model is said to be the ideal model to be used in most MANET's study. This is because when considering a ground reflected propagation path between transmitter and receiver, two ray ground is more practical than the free space model[16]. This RPM is considering both the direct path and ground reflection path. The two-ray ground reflection principle is generally a multipath radio propagation model that predicts path losses between a transmitting antenna and a receiving antenna when they are in line of sight (LOS) [1, 17]. As a result, nodes are positioned on a plane as illustrated in Figure 5.

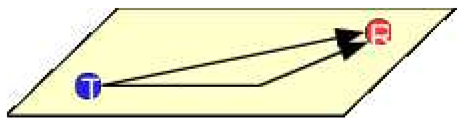

Fig. 5. Two Ray Ground propagation model [16]

As stated in previous existing research [14, 15], it is mainly useful and more accurate for predicting the received power, Pr(d), at a long distances from the transmitter in two ray ground model. The received power at distance, , is predicted by Equation (2) below, where ht and hr are the heights of the transmitter and receiver antennas. The distance between the transmitter and the receiver is annotating as d. Gt and Gr are the gains of the receiving and the transmitting antennas respectively. In order to ensure the free space model is consistent, L, which is the system loss is added. Equation (2) shows a faster power loss than Equation (1) as the distance are increasing. This is because the farther the distance between transmitter and receiver, the faster the power loss will be.

$$Pr(d) = \frac{Pt\ Gt\ Gr\ ht^2 hr^2}{d^4\ L} \tag{2}$$

This RPM induced oscillation by the constructive and destructive combination of the two rays which causes it not providing a good result for a short distance[17]. It gives more accurate prediction at a long distance but not for a short distance. So, free space model is still used when the distance, , is small. However, every type of RPM has different performance based on the traffic on road. Each type ofRPM, however, has different output depending on road traffic. So, this model may be sufficient for most traffic, but not all road traffic.

C. Nakagami Propagation Model

The best to describe Nakagami radio propagation model is the mathematical general modeling of a radio channel with fading. It was found by existing research in [19] that this model has more configurable parameters. This model is also used to classify the statistics of signals transmitted over the multipath fading channel since it can flexibly model various fading conditions[13].The aim is to enable the wireless communication channel to be more closely represented, which could define various parameter values. Nakagami is considered as a stochastic [13] model which is a method for estimating probability distributions of possible results by allowing one or more inputs to differ randomly over time [13, 17]. Nakagami distribution is applied to the power level and defined by the function of probability density as in Equation (3) with 'm' indicates the fading depth parameter and 'ω' as the average received power [13].

$$f(x;\ \mu,\omega) = \frac{2\mu^2}{\Gamma(\mu)\,\omega^{\mu}}\,x^{2\mu-1}\,exp^{-\frac{\mu}{\omega}x^2} \qquad (3)$$

The corresponding probability distribution function (pdf) of power at the given distance can be obtained by modifying variables and gamma distributions. As a stochastic model, the signal power follows a gamma distribution with two parameters: the average power fading, ω=[x^2], and the severity of fading, μ>0, where the channel amplitude is $x \geq 0$[13].

Nakagami's numerical form is systematically controllable, which makes it more rational for wireless networks to model fading. The fading model of Nakagami corresponds to experimental results for short wave ionospheric propagation, which is critical for model intrusion from various sources. The variations in the generated signal strength and the average power changes are caused by the increasing distance between vehicles at the intersection. The goal of this is to resolve interferences that are normal in urban traffic today, such as buildings and automobiles[18].

VANET has been regarded as a promising technique that can help tracking and enhancing the safety and efficiency of traffic on-the-road technology between vehicles [12].In VANET, the main concern is the obstacles for the communication between vehicles and RSUs such as the buildings along the road. Hence, the concept of RPM is used as one of the main factors for the communication in VANET. However, there are various type of RPM which contain different algorithm for each and resulting to different results and uses for each RPM. Thus, this project aims to evaluate the best performance of different type of RPM at a selected traffic area by using a simulation based study. The main problem to conduct the research is the inability to perform the observation on the real vehicle to learn about the RPM cases in VANET protocol. So like most researches, network simulator which is a useful alternative for the actual deployment has been used in this research because of the accurate and precise study. The analysis of three RPM performances which are Free Space, Two Ray Ground and Nakagami model has been identified by usingNS-2 along with three other software tools, JOSM, SUMO and MOVE.

II. METHODOLOGY

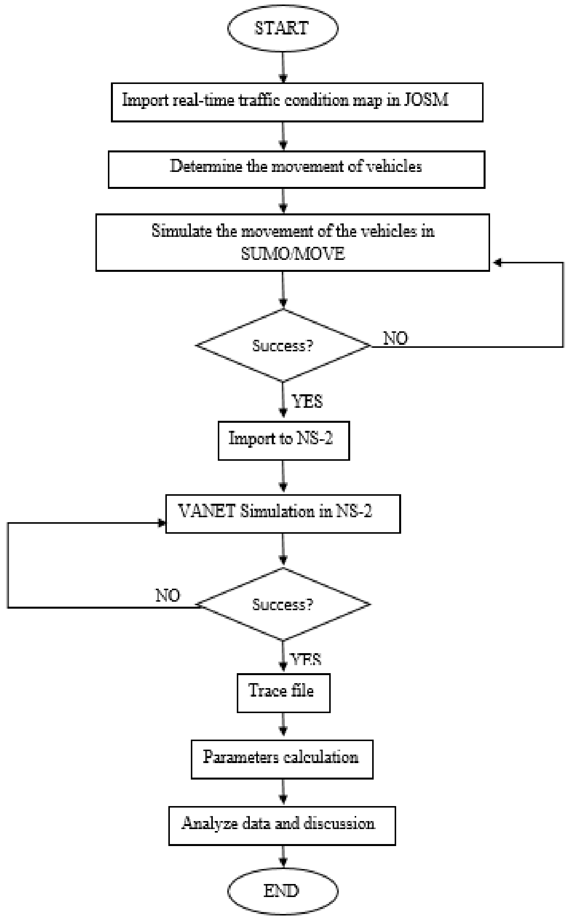

Fig. 6. Flowchart of the simulation process

All of the simulations of the planning stages are illustrated based on a flowchart in Figure 6. Once Ubuntu was installed, the simulation process was started with JOSM. The desired target location must be determined and downloaded by using JOSM. Then, the (.osm) file was converted to (.xml) file in order to be used in SUMO. Files like (.net.xml) and (.rou.xml) need to be generated by using command line interface at terminal. Next, in SUMO the route must be defined as well as determining the movement and amount of vehicles which then created some files such as (sumoTrace.xml) and (sumo.cfg) which were important in order to perform final simulation. In MOVE, the file created from SUMO has been transported to simulate the movement of vehicles based on real time; real world. NS-2 as the final simulation process used to obtain necessary data.

Figure 7 shows the simulation of VANET in NS-2 after the configuration and conversion process performed at the beginning stage by using JOSM, SUMO and MOVE software. The circle waves in Figure 8 indicate the nodes interaction between each other at the targeted area of 4-way intersection junction, Jalan Besar Selayang Baru. Figure 9 shows the 2D version of this Baru map. Based on this map, it can be seen that there is a 4-way intersection junction with four traffic lights altogether at the targeted area. The real map image was downloaded in JOSM software within 2 km x 2 km size of network area. Note that, this map has been generated in SUMO from the traffic simulation that has been configured in MOVE previously. It can be seen in the map the real time movements of vehicles on the road where the yellow boxes in the map are representing the vehicles which the amount of vehicles to be simulated has been set during configuration before. In order to simulate, the delay has to be set up in order to capture clearly the movement of vehicles.

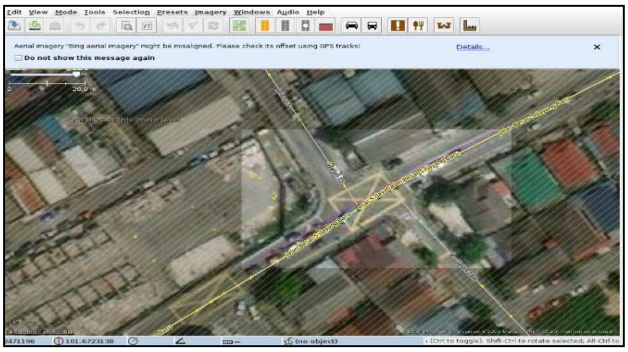

Fig. 7. Map of Jalan Besar Selayang Baru in JOSM (Bing Aerial Image)

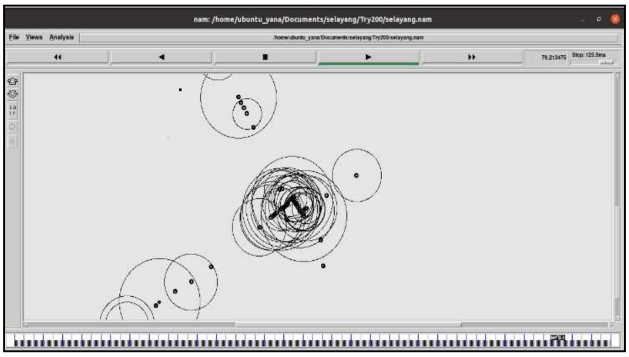

Fig. 8. Simulation Process in NS-2

Fig. 9. The Simulation of Jalan Besar Selayang Baru in SUMO

The simulation and analysis of three RPM performances has been conducted with few parameters for observation as shown in Table I. The simulations are conducted for six times according to different number of vehicles for each type of RPM which are 50, 60, 70, 80, 90 and 100 vehicles. For connections that carry traffic at a constant bit rate, CBR was used for the simulation, where there is an implicit dependency on time synchronization between the source of traffic and the destination[19]. Traffic modelling which is CBR used in NS-2 along with the transport protocols, TCP and UDP, in order to design the traffic source behaviour of packets. Ad-hoc On-Demand Distance Vector Routing[20, 21], one type of routing protocol used was a MANET-related reactive routing protocol that establishes a path to the destination by transmitting route request packets across the entire network[22].

TABLE 1. THE PARAMETERS FOR THE SIMULATION ANALYSIS

Parameters	Specifications
Propagation Model	Free Space, Two Ray Ground, Nakagami
Visualization Tools	NS-2
Network Area	2 km x 2 km
Radio Range	DSRC
No. of Vehicles	50, 60, 70, 80, 90 and 100 vehicles
MAC Layer	IEEE 802.11p
Ad-hoc Routing	AODV
Channel Type	Wireless Channel
Traffic Type	CBR
Simulation Time	1000 milliseconds
Speed of vehicle	Random

III. RESULT AND DISCUSSION

The experimental analysis is the evaluation in the impact of the RPM in form of graph presentation. Few parameters have been taken to measure the relationship of variables that could affect the performances of RPM in VANET which is throughput, packet loss delivery and end-to-end delay. Here, the impact of RPM on VANET has been analysed using the AODV protocol with different parameters.

i. Average Throughput

The pattern of Free Space, Two Ray Ground and Nakagami model based on throughput is shown in Table II. All RPMs have a decreasing value of throughput upon the increasing number of vehicles which can be conclude that all RPMs fulfil the theoretical concept of throughput where the more the number of nodes communication, the lower the amount of throughput will be.

TABLE II. THE RESULT OF THROUGHPUT (KBPS) FOR THREE RPMS

No. of Nodes	Free Space	Two Ray Ground	Nakagami
50	3.76	13.16	16.21
60	5.98	18.14	26.67
70	7.16	34.84	7.16
80	8.73	36.95	63.10
90	9.64	52.28	63.03
100	5.88	49.20	8.93
Total Average	6.86	34.10	31.85

The performance of Free Space, Two Ray Ground and Nakagami model can be analysed that Free Space model has the highest throughput result with a total average throughput of 306.97kbps as illustrated in Figure 10. As the ratio of packet numbers obtained by the destination node implies throughput, the RPM that scored the highest throughput value is regarded as the best performer in terms of throughput based on the simulation. Two Ray Ground model was at second place in term of throughput performance with only 0.73 kbps difference. With this, Two Ray Ground was still considered having one of the best performance of throughput on VANET. Nakagami model performed the least performance of throughput at Jalan Besar Selayang Baru with only 267.52 kbps of total average value.

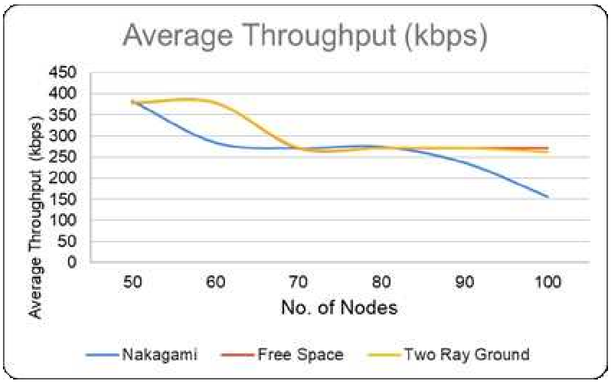

Fig. 10. The Graph Result of Throughput for three RPMs

ii. End-to-End Delay

Based on Table III, the result of packet loss for three different RPMs can be observed. The end-to-end delay of packet delivered have been calculated in milliseconds. The result can be determined that Two Ray Ground and Nakagami model have the higher results than Free Space model.

TABLE III. THE RESULT OF END-TO-END DELAY (MS) FOR THREE RPMS

No. of Nodes	Free Space	Two Ray Ground	Nakagami
50	0.09%	0.37%	1.26%
60	0.07%	0.11%	2.73%
70	0.21%	1.48%	0.31%
80	0.33%	0.50%	3.44%
90	0.23%	0.40%	3.84%
100	0.23%	0.43%	0.24%
Total Average	0.19%	0.55%	1.97%

The analysis of three RPMs performance can be analyzed based on the graph illustrated in Figure 11. Free Space model scored the best performance evaluation as the lowest delay time for node communication. Free Space has the total average value of end-to-end delay with 6.86ms, which means it performed fastest in term of end-to-end delay of packet between communication of vehicles and RSUs. However, due to the high delay between communication with corresponding nodes, Two Ray Ground model performs the worst delay characteristics with a cumulative average delay of 34.10ms while Nakagami model with 31.85ms performed faster performance in term of delay time for communication between nodes. This could probably happen because Free Space ignores more obstacles on the road compared to the other RPMs.

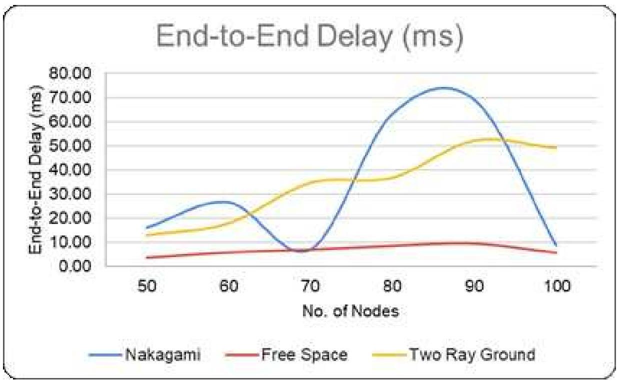

Fig. 11. The Graph Result of End-to-End Delay for three RPMs

iii. Packet Loss

Table IV shows the packet loss result for Free Space, Two Ray Ground and Nakagami model. The results of packet loss were observed in percentage of the whole packet loss for every different amount of nodes.

TABLE IV. THE RESULT OF PACKET LOSS FOR THREE RPMS

No. of Nodes	Free Space	Two Ray Ground	Nakagami
50	379.00	380.2	382.51
60	379.04	379.07	284.02
70	270.95	273.19	274.50
80	270.94	271.49	270.94
90	270.94	271.30	236.64
100	270.94	262.17	156.51
Total Average	306.97	306.24	267.52

From Figure 12, it can be concluded that Free Space model has the best performance in term of packet loss as it has the same rate of packet loss for communication between every amount of vehicles which all is lower than 1% making it performed better with cumulated range only 0.19% for the whole data. While Two Ray Ground has a total average of 0.55%, it still considered as one of the best performance in terms of packet loss as the value is less than 1%. For this case, Nakagami has the poor performance as it scored the highest value of total average packet loss ,1.97%, which this means more packets which were to be delivered during communication of vehicle at Jalan Besar Selayang Baru were lost. This is because Nakagami are considering many factors of obstacles on the road.

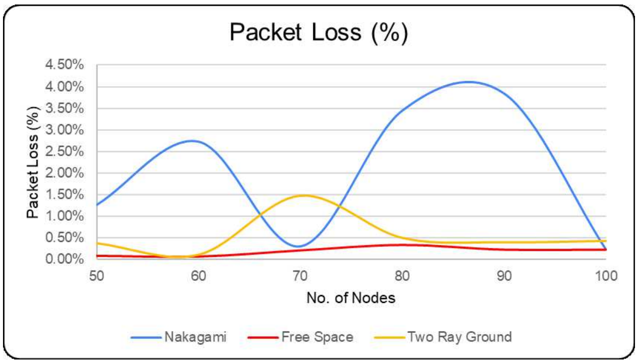

Fig. 12. Graph Result of Packet Loss for three RPMs

Based on overall results of throughput, end-to-end delay and packet loss for all three models of RPM, it can be concluded that Free Space model has the best performance of RPM in term of simulation. This is because Free Space model performs a better performance for the communication between vehicles and RSUs as it has the lowest value of the end-to-end delay and packet loss. Plus, Free Space model also recorded as the highest amount of throughput making it performed the best in terms of throughput because it ignores more obstacles on the road. Due to the greatest amount of delay and loss of packet data with corresponding nodes, Nakagami model was found to have the poor performance of VANET at Jalan Besar Selayang Baru. This is because Nakagami are considering many factors of obstacles on the road, so that is why in the simulation Nakagami seems to perform the worst. However, one must know that the performance of RPM for different type or condition of traffic could be vary.

IV. CONCLUSION

VANET, an evolving form of ad hoc network has now played a significant role in terms of technology. The VANET application has been commonly used as interaction between vehicles with RSUs for traffic control, warning purposes and navigation. Hence, this paper is proposed to prove that radio propagation model (rpm) is one of the key factor of VANET protocol performance. The analysis on the performance of the RPM has been conducted by using NS-2 with other supporting simulation tools which are JOSM, MOVE and SUMO. There are few types of RPM which can help in the performance of routing protocols for VANET. However, it can be concluded that Free Space model is the most suitable RPM to be used at Jalan Selayang Baru, Batu Caves in term of simulation because it ignores too many obstacles but Nakagami could have performed better performance in real life as they consider more obstacles. It can also be concluded that different type of RPM could have different performance on any targeted traffic area. The objective of this research has been achieved successfully by the end of the research. Since VANET application is one of the biggest solution to resolve on road accidents and issues, so this application should be constantly improved for better from time-to-time.

ACKNOWLEDGEMENT

The authors would like to thank the Ministry of Higher Education and Universiti Teknologi MARA Shah Alam for the grant support in publishing this paper. The grant ID is 600-RMC/GPK 5/3 (248/2020).

REFERENCES

[1] M. A. Al-Absi, A. A. Al-Absi, and H. J. Lee, "V2V communication modeling for environmental channel throughput and radio propagation," in 2017 International Conference on Information and Communication Technology Convergence (ICTC), 18-20 Oct. 2017 2017, pp. 507-512, doi: 10.1109/ICTC.2017.8191029.

[2] M. Al-Absi, A. Absi, T. Kim, and H. Lee, "An environmental channel throughput and radio propagation modeling for vehicle-to-vehicle communication," International Journal of Distributed Sensor Networks, vol. 14, p. 155014771877253, 04/01 2018, doi: 10.1177/1550147718772535.

[3] A. Dak, S. Yahya, and M. Kassim, "A Literature Survey on Security Challenges in VANETs," International Journal of Computer Theory and Engineering, pp. 1007-1010, 01/01 2012, doi: 10.7763/IJCTE.2012.V4.627.

[4] M. A. Qureshi, R. Md. Noor, A. Shamim, S. Band, and K.-K. R. Choo, "A Lightweight Radio Propagation Model for Vehicular Communication in Road Tunnels," PLoS ONE, vol. 11, 03/22 2016, doi: 10.1371/journal.pone.0152727.

[5] S. F. Dessai and D. Sutar, "Radio propagation model with obstacle effect and efficient bandwidth utilization for V2V VANET application services," in 2019 International Conference on Intelligent Computing and Control Systems (ICCS), 15-17 May 2019 2019, pp. 602-606, doi: 10.1109/ICCS45141.2019.9065612.

[6] W. Young et al., "Measurements and Models for the Wireless Channel in a Ground-Based Urban Setting in Two Public Safety Frequency Bands," 01/12 2021.

[7] Y. Wang, J. Hu, Y. Zhang, and C. Xu, "Reliability evaluation of IEEE 802.11p-based vehicle-to-vehicle communication in an urban expressway," Tsinghua Science and Technology, vol. 20, no. 4, pp. 417-428, 2015, doi: 10.1109/TST.2015.7173456.

[8] D. Jiang and L. Delgrossi, IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments. 2008, pp. 2036-2040.

[9] S. Rehman, M. A. Khan, T. Zia, and L. Zheng, "Vehicular ad-Hoc networks (VANETs)—An overview and challenges," Journal of Wireless Networking and Communications, vol. 3, pp. 29-38, 01/01 2013, doi: 10.5923/j.jwnc.20130303.02.

[10] G. Luo et al., "Cooperative vehicular content distribution in edge computing assisted 5G-VANET," China Communications, vol. 15, no. 7, pp. 1-17, 2018, doi: 10.1109/CC.2018.8424578.

[11] M. Wang, H. Shan, L. X. Cai, N. Lu, X. Shen, and F. Bai, "Throughput capacity of VANETs by exploiting mobility diversity," in 2012 IEEE International Conference on Communications (ICC), 10-15 June 2012 2012, pp. 4980-4984, doi: 10.1109/ICC.2012.6364316.

[12] C. Boucetta, O. Baala, K. A. Ali, and A. Caminada, "Performance of topology-based data routing with regard to radio connectivity in VANET," in 2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC), 24-28 June 2019 2019, pp. 609-614, doi: 10.1109/IWCMC.2019.8766456.

[13] M. Hadzialic, N. Behlilovic, and A. Sarajlic, "An Analytical Approach to Error Evaluation in Gamma Shadowed Nakagami-m Fading Channel for Different Path Loss Models," in Proceedings ELMAR 2006, 7-10 June 2006 2006, pp. 273-277, doi: 10.1109/ELMAR.2006.329565.

[14] R. Chandra, "Performance Evaluation of Radio Propagation Model For Vehicular Ad Hoc Networks Using VanetMobiSim and NS-2," International Journal of Distributed and Parallel systems, vol. 3, pp. 145-155, 07/31 2012, doi: 10.5121/ijdps.2012.3415.

[15] M. Eenennaam, "A Survey of Propagation Models used in Vehicular Ad hoc Network (VANET) Research," 01/01 2009.

[16] F. J. Martinez, C. Toh, J. Cano, C. T. Calafate, and P. Manzoni, "Realistic Radio Propagation Models (RPMs) for VANET Simulations," in 2009 IEEE Wireless Communications and Networking Conference, 5-8 April 2009 2009, pp. 1-6, doi: 10.1109/WCNC.2009.4917932.

[17] P. K. Singh, "Influences of TwoRayGround and Nakagami propagation model for the performance of adhoc routing protocol in VANET," International Journal of Computer Applications, vol. 45, no. 22, pp. 1-6, 2012.

[18] H. Brahmia and C. Tolba, "Nakagami Fading Impact on the Performances of VANET Routing Protocols in a Realistic Urban," International Journal of Advanced Networking and Applications, vol. 11, pp. 4330-4335, 01/01 2020, doi:10.35444/IJANA.2020.11042.

[19] H. Chan, "A Dynamic Reservation Protocol For Integrating Cbr/vbr/abr Traffic Over Ieee 802.14 Hfc Networks," vol. 5, 10/15 1998, doi: 10.1109/GLOCOM.1998.776644.

[20] S. Khelifa and Z. M. Maaza, "An Energy Multi-path AODV routing protocol in ad hoc mobile networks," in 2010 5th International Symposium On I/V Communications and Mobile Network, 30 Sept.-2 Oct. 2010 2010, pp. 1-4, doi: 10.1109/ISVC.2010.5656146.

[21] J. Ledy, H. Boeglen, B. Hilt, A. Abouaissa, and R. Vauzelle, "An enhanced AODV protocol for VANETs with realistic radio propagation model validation," in 2009 9th International Conference on Intelligent Transport Systems Telecommunications, (ITST), 20-22 Oct. 2009 2009, pp. 398-402, doi: 10.1109/ITST.2009.5399320.

[22] H. Jhajj, R. Datla, and N. Wang, "Design and Implementation of An Efficient Multipath AODV Routing Algorithm for MANETs," in 2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC), 7-9 Jan. 2019 2019, pp. 0527-0531, doi: 10.1109/CCWC.2019.8666607.