ISSN 1870-4069

Vehicular Ad-Hoc Network Throughput Evaluation in 3D Environments

Josefina Castañeda-Camacho, Alejandro Sánchez-Mendoza,
Ana María Rodríguez-Domínguez, José Fermi Guerrero-Castellanos

Benemérita Universidad Autónoma de Puebla,
Facultad de Ciencias de la Electrónica,
Mexico

alejandro.sanchezme@alumno.buap.mx

Abstract. The deployment of the 5th generation of mobile communication networks (5G) brought countless opportunities to improve and create technologies for everyday use. Autonomous aerial vehicles such as drones (UAVs) or their terrestrial counterpart, rovers (UGVs) are systems that have appeared in both private and public sectors to offer different services. Vanets are self-organizing and dynamic networks designed specifically for vehicle communication in changing environments. This paper shows an analysis of one of the most important metrics in network design, the throughput, in a vanet network environment using Montecarlo discrete event simulations. The performance of different modulation methods and how the conditions of the communication channel affect the throughput are analyzed with the main goal to define which of the modulation methods is better for each channel conditions.

Keywords: Vehicular Ad-hoc networks, throughput evaluation, 5G.

1 Introduction

Since the appearance of the human species, communication processes have been essential for its survival and growth, in modern times this has not changed. An example of these are mobile communication networks that have been transformed since their invention in search of improving their performance and efficiency [1].

The fifth generation of mobile communication networks or 5G as it is commonly known, is today a reality and brings with it improvements in network speed, in the use of bandwidth and in the number of devices supported by the network, among others [9].

The use of both terrestrial (AGV) and aerial (UAV) autonomous vehicles to carry out different tasks in public and private sectors has increased in the last decade, this is mainly attributed to the fact that the price of these devices have become cheaper.

As a result of the growth of these technologies, new needs have arisen, one of which is to intercommunicate these vehicles efficiently to improve their performance and avoid any type of failure. Ad-Hoc vehicular networks (vanet) emerge as a solution to this need thanks to the benefits offered by 5G [2].

pp. 215–222; rec. 2022-08-14; acc. 2022-09-24

Table 1. Comparison of Parameters Considered by Referenced Works.

Reference	Parameters
[3]	Throughput / SIR
[7]	Throughput / SIR
[9]	Outage Probability

Vanets are a particular case of mobile Ad-Hoc networks (manets) focused on vehicular environments. A vanet is a wireless network characterized by allowing the nodes to communicate cooperatively, to exchange relevant information such as road conditions or situations that arise during a journey, providing a self-organized network environment that does not require an established infrastructure or centralized administration [7].

Ideally, a communications network should be simple, flexible, and cost-effective, but robust enough to support the traffic that flows through it. To find the conditions in which a network approaches optimal performance, it is necessary to carry out a process of network sizing.

The sizing of a network is the design process through which the minimum capacities that each segment of the network must have to satisfy the operation requirements and ensure the quality of service to users are determined [3, 8].

There are many parameters that can be measured during network sizing, one of the most important is the throughput, this metric gives an idea of the total quantity of date would be possible to transmit along the communication network [4]. Table 1 present a resume of the parameters used for different authors to evaluate vehicular adhoc networks.

This work is focused on the measurement of the throughput of a vanet. Present work is structured as follows. Second section presents the mathematical background used to develop the simulation scenarios. Third section includes the simulation set-up and results. Lastly conclusions are presented.

2 Mathematical Background

The simulation algorithm is composed by three fundamental calculations, first the power received by each mobile user inside the network working area and in the interference cells, secondly, the signal-to-interference ratio using the calculated power from the interfering users and lastly the throughput for each communication link according to its obtained SIR value.

Equation 1 shows the proposed propagation model, it is a modification of the free space propagation model, in this case the received power evaluation considers the shadowing effects, distance losses and transmitter antenna gain (as a function of the user position), this helps to measure the power losses related to the transmission of the data through the propagation medium:

$$P_{rx} = P_{tx} G_{tx} G_{rx} \frac{h_{tx} h_{rx}}{d^{\mu}} 10^{\frac{\lambda}{10}}, \quad (1)$$

where P_{tx} is the transmission power, G_{tx} and G_{rx} are the antenna gains for the transmitter and the receiver respectively, d is the distance between the antenna and

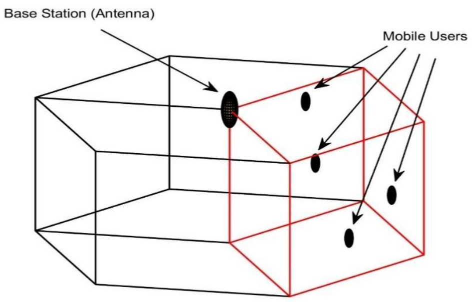

Fig. 1. Network Communication Cell.

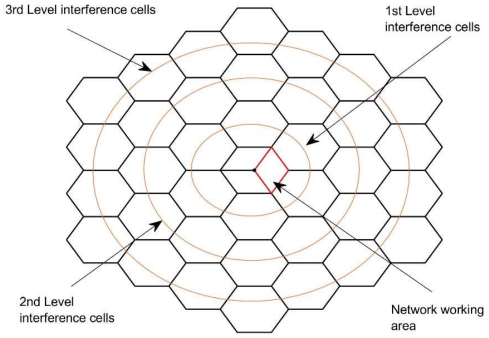

Fig. 2. Hexagonal Cell Regions.

the end device, μ is the propagation losses exponent, h_{tx} and h_{rx} are the transmitter and receiver antenna height , finally, λ is the characteristic Gaussian random variable of the log-normal distribution which models the shadowing effects.

The transmitted antenna gain is considered as a parabolic function which depends on the angle $\phi_{l,n}$ between the end device and the maximum transmission ray of the antenna, this function is expressed in equation 2:

$$G_{tx}(\phi_{l,n}) = \begin{cases} 1 - \frac{1-q}{\left(\frac{\pi}{3}\right)^2}\phi_{l,n}^2 & si|\phi_{l,n}| \leq \sqrt{\frac{1-p}{1-q}}\frac{\pi}{3} \\ p & si|\phi_{l,n}| > \sqrt{\frac{1-p}{1-q}}\frac{\pi}{3} \end{cases}, \tag{2}$$

where q represents the gain level of the antenna inside the maximum transmission sector and p is the mean normalized gain of the side lobes [5, 6].

Then, once the received power is calculated, the signal-to-interference is obtained as a quotient between the received power by the mobile user in the working area and the summation of the received power by the interfering nodes in the adjacent cells, as shown in equation 3:

$$SIR_i = \frac{P_{rx_i}}{\sum_{k=1}^{N_{int}} P_{rx_k}}, \tag{3}$$

Table 2. Transmission Parameters.

Parameter	**Value**
Transmission Power	89.1 mW
Sensitivity	1.9 pW
Bandwidth	10 MHz

where P_{rx_i} is the received power by $i-th$ mobile user inside the interest area, N is the number of interfering users and P_{rx_k} is the power received by the $k-th$ interfering user. Signal-to-interference ratio helps to understand the impact of the interference caused by nearly communications happening around the network working area.

Lastly, to calculate the communication link throughput, it is necessary to start from the link quality metric γ, given as a function of the bit energy and the spectral density of the interference, as shown in equation 4:

$$\gamma = \left(\frac{E_b}{I_0}\right)_i = \frac{\omega_0}{R_i} SIR_i, \tag{4}$$

where E_b is the bit energy, I_0 is the spectral density of the interference, ω_0 is the system bandwidth, R_i is the $i-th$ user throughput and SIR_i is the $i-th$ user Signal-to-Interference Ratio.

Throughput refers to the total quantity of bits per second transmitted form the sender to the receiver and it can be modified depending on the modulation scheme used by the system. Equation 5 shows how throughput is calculated:

$$R_i = \begin{cases} \left(\frac{\omega_0}{\gamma}\right) SIR_i & siSIR_i > m\gamma \\ m\omega_0 & siSIR_i \leq m\gamma \end{cases}, \tag{5}$$

where m is a factor related to the modulation scheme and γ is the channel quality metric, when γ increase it means the channel conditions are worst, communications standards implemented for vanets commonly permit four modulations, BPSK, QPSK, 16QAM and 64QAM; m takes 1, 2 ,4 and 6 as its value respectively for each modulation.

3 Simulation Set-Up

We have developed a discrete event Montecarlo simulation to evaluate the equation (5). For the simulation scenario, we are considering a communication environment divided in micro-cellular cells modeled as hexagonal prisms as shown in figure 1.

The network is formed by four mobile users' ash shown in figure 1. The simulation occurs in a single cell with a 10mts radius and 3 meters height. Also, considering a 120 degrees sectorization.

This sector matches with the antenna propagation pattern placed in the center of the cell. Similar scenarios are created for the adjacent cells and interfering users, this shown in figure 2. Results obtained from the simulation are shown in the following section.

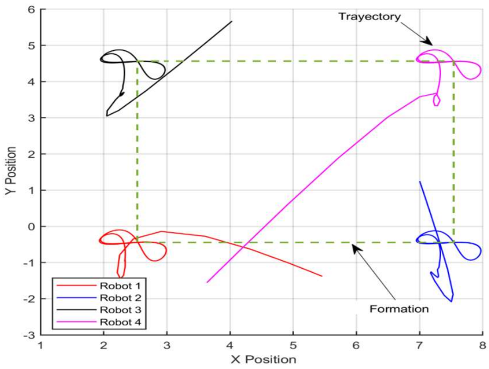

Fig. 3. Nodes Movement Trajectories.

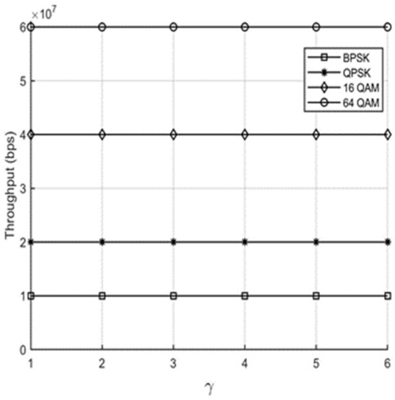

Fig. 4. Throughput Behavior for Node 1.

4 Results

4.1 Mobility

To simulate node mobility a control algorithm for trajectory and formation following was implemented, with random initial conditions, the nodes are commanded to bring a square formation and follow the Bernoulli's lemniscate trajectory, figure 3 shows the trajectory followed by the nodes in one of the events.

4.2 Throughput

Considering that the maximum transmission ray of the transmitting antenna matches with the X axe in 0 value, robot number 1 and 3 have a better positioning compared with robots 2 and 4, figure 4 shows the throughput behavior for robot 1.

In this case the bandwidth usage is the maximum possible for all four modulations and all channel conditions (γ), one of the reasons is that the distance between the user

Table 3. Throughput for $\gamma = 1$.

USER	BPSK	QPSK	16QAM	64QAM
1	10 Mbps	20 Mbps	40 Mbps	60 Mbps
2	10 Mbps	20 Mbps	40 Mbps	60 Mbps
3	10 Mbps	20 Mbps	40 Mbps	60 Mbps
4	10 Mbps	20 Mbps	40 Mbps	60 Mbps

Table 4. Throughput for $\gamma = 3$.

USER	BPSK	QPSK	16QAM	64QAM
1	10 Mbps	20 Mbps	40 Mbps	60 Mbps
2	10 Mbps	20 Mbps	39.6 Mbps	54 Mbps
3	10 Mbps	20 Mbps	40 Mbps	59.6 Mbps
4	10 Mbps	19.6 Mbps	28.9 Mbps	32.8 Mbps

Table 5. Throughput for $\gamma = 6$.

USER	BPSK	QPSK	16QAM	64QAM
1	10 Mbps	20 Mbps	40 Mbps	60 Mbps
2	10 Mbps	19.9 Mbps	34.6 Mbps	39.6 Mbps
3	10 Mbps	20 Mbps	39.6 Mbps	55.3 Mbps
4	9.9 Mbps	16.3 Mbps	20.6 Mbps	23.1 Mbps

and the antenna is short and losses are minimum, in the other hand, in figure 5, the throughput behavior for node 4 is shown.

The impact of the distance and the angle between the transmitter and the receiver is clear. Impacts increase when the channel conditions are poor and the modulation complexity increase, this let us know that modulation schemes such as 16 QAM and 64 QAM present a higher sensitivity to channel conditions than BPSK and QPSK, however, channel usage is better in 16 QAM and 64 QAM.

Finally, tables 2, 3 and 4 show throughput values for all modulations with channel conditions equal to 1, 3 and 6.

Once results are obtained it is important to compared them with results reported for similar works in the literature related. Table 6 shows a comparison between the results already presented and some relevant data detailed by other authors.

5 Conclusion

Results show that the throughput can be significantly affected by channel conditions, users' mobility, and the modulation scheme. It is hard to determine which modulations scheme is better than the other, it would depend on the network working area conditions. Also, is important to remark that the complexity of a 64 QAM or 16 QAM system is considerably higher than a BPSK or QPSK system, this impacts directly in the cost of the network implementation.

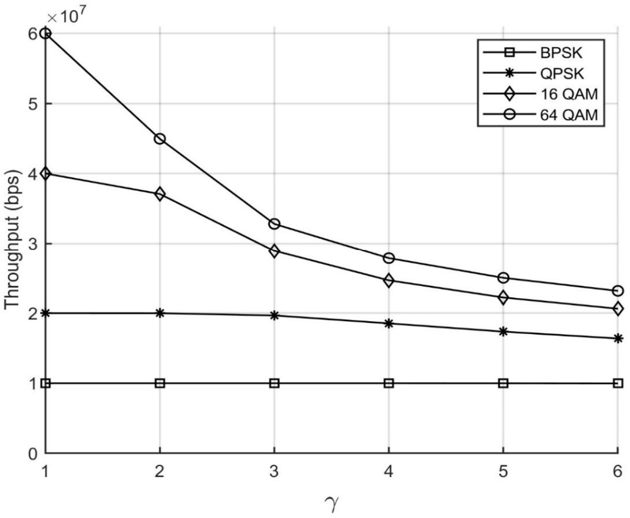

Fig. 4. Throughput Behavior for Node 4.

We can say that in general terms 64 QAM offers the best behavior when talking about channel usage or throughput compared to 16 QAM, QPSK and BPSK, but this would not be enough to determine which scheme is better to implement in a real-world scenario, it would be necessary to analyze other network and environmental metrics, also, a system supporting different modulation schemes can be possible.

Comparing the results obtained and the data report in other works for example in [7] a vanet is evaluated and throughput results are reported, the main difference is the coverage area simulated, in [7] the network cell has a 1km radios, obtaining significantly less bandwidth usage, for 64 QAM the maximum throughput obtained is 20.6 Mbps while in this work que maximum throughput for the same modulation is 60 Mbps. This confirms what we said before, the mobility and positioning affect considerably the network performance.

References

1. Brito-Gómez, J.: Evolución de las redes móviles hasta hoy en día y el impacto de la red móvil de quinta generación. Revista ReDTis, vol. 3, no. 3 (2019) http://www.redtis.org/index.php/Redtis/article/view/36
2. VIU Internacional: Evolución de la red de comunicación móvil, del 1G al 5G. Universidad Internacional de Valencia (2018) https://www.universidadviu.com/int/actualidad/nuestros-expertos/evolucion-de-la-red-de-comunicacion-movil-del-1g-al-5g
3. García-Santiago, A.: Diseño e implementación de una red de comunicaciones para el control de formación de vehículos aéreos no tripulados. Benemérita Universidad Autónoma de Puebla (2018) https://hdl.handle.net/20.500.12371/8205
4. Paul, A., Chilamkurti, N., Daniel, A., Rho, S.: Evaluation of vehicular network models. Intelligent Vehicular Networks and Communications, pp. 77–112 (2017) doi: 10.1016/B978-0-12-809266-8.00004-1

5. ITU: Comitted to connecting the world: Network dimensioning and configuration. Unión Internacional de Telecomunicaciones (2001) https://www.itu.int/itudoc/itud/dept/psp/ssb/mpg/ch07.pdf
6. Pióro, M., Medhi, D.: Routing, flow, and capacity design in communication and computer networks. The Morgan Kaufmann Series in Networking, pp. 679–711(2004) doi: 10.1016/B978-012557189-0/50024-X
7. Villegas-Hernández J. C.: Diseño de una plataforma de simulación para la evaluación del desempeño de un sistema celular OFDMA con estaciones base móviles. Benemérita Universidad Autónoma de Puebla (2020)
8. Castañeda-Camacho, J., Rios, C., Lara-Rodriguez, D.: Reverse link erlang capacity of multiclass CDMA cellular system considering nonideal antenna sectorization. IEEE Transactions on Vehicular Technology, vol. 52, no. 6, pp. 1476–1488 (2003) doi: 10.1109/TVT.2003.816629
9. Castañeda-Camacho, J., Sánchez-Mendoza A., Hernández-Rodríguez, D., Saviñón-López, R., Rodríguez-Domínguez, A. M., Maya-Rueda, S. E., Mino-Aguilar, G.: 5G downlink power quality evaluation for 3D environments. In: Artículos del Congreso Internacional de Investigación Academia Journals, vol. 13, no. 10, pp. 455-460 (2021)