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Performance Evaluation of Vehicle Ad hoc Networks Under Wi-Fi-6 Technology

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Abstract

Vehicle ad hoc networks are considered mobile networks where the nodes are mobile objects and can change their positions within an environment over time. These objects can be connected at any time according to a predefined strategy. Simulating this kind of network needs high attention to many details. Moreover, the literature lacks works that describe the requirements of simulating such networks. Therefore, this work tries to describe the requirements of simulating vehicle networks (VANETs). Moreover, the goal is to determine what is needed to simulate vehicle networks in terms of the distribution of vehicles, the movement patterns, and the routing protocols used. The simulation results show interesting facts about the VANET networks and the best strategies to minimize the consumption of network resources. Finally, this work considers two communication technologies among network nodes; Wi-Fi 5 and Wi-Fi 6.

Keywords:
VANET, Wi-Fi 5, Wi-Fi 6, Mobility Models, Simulation Requirements

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1. INTRODUCTION

1.1 Overview

As known, Ad-Hoc Networks are irregular networks, which are user-friendly to any network node. These networks have several types such as VANETs, MANETs, and new FANETs [1]. The VANET is considered one of the extraordinary types of Ad-Hoc networks. The VANET is a self-organized network, where every node has high portability to adapt to the network, the topology changes frequently and rapidly [2]. This technique consists of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications that use wireless access technologies such as IEEE 802.11[3]. The befits of the VANET are to improve road safety and motor traffic efficiency in order to develop the Intelligent Transport Systems (ITS).

The applications of VANETs can be classified into several categories [4] as follows:

- Safety Applications: the applications that are used to increase transportation safety in urban areas.
- Efficiency Applications: the applications that are used to detect the location of vehicles to improve the mobility of the vehicle in urban areas.
- Comfort Applications: used to make trips more comfortable and enjoyable.
- Interactive Entertainment: used to distribute and deliver entertainment-related information to drivers and passengers.
- Urban Sensing: used for urban monitoring and sharing data of common interest.

There are many wireless techniques used in VANETs networks such as Cellular Systems (2G/3G/4G), WiMAX Standard, MICROWAVE, WLAN/Wi-Fi Standards, etc. [5]. The WLAN/Wi-Fi standard is one of the most techniques used in VANETs due to high data transfer rates, low cost, and ease of deployment. Moreover, there are several standards of Wi-Fi, such as 802.11a, 802.11ac, 802.11b, 802.11e, 802.11g, and 802.11n. Recently, the Wi-Fi technology has been developed to move from Wi-Fi 5 to what is now known as Wi-Fi 6. The difference between the two standard technologies is presented in Table 1 [6]:

Table 1: The main differences between Wi-Fi 5 and Wi-Fi 6.

Feature	Wi-Fi 5 (802.11ac)	Wi-Fi 6/Wi-Fi 6 E (802.11ax)
Data rate	Up to 7 Gbps	Up to 9.6 Gbps
Channel Bandwidth	20, 40, 80, 80 + 80, 160	20, 40, 80, 80 + 80, 160
Frequency	OFDM	OFDM and OFDMA
OFDMA	N/A	DL and UL
Radios	MU-MIMO (DL) (8x8)	MU-MIMO (DL & UL) (8x8)
Coverage range	<50 m indoor, up to 50 m outdoor	<50 m indoor, up to 300 m outdoor
Specific frequencies	2.4 and 5 GHz	2.4 GHz, 5 GHz, 6 GHz, 60 GHz

Furthermore, simulating VANET networks needs a lot of requirements to be considered before the simulations are carried out. For instance, how do the nodes move within the simulation environment? Under which routing protocol the messages are exchanged among nodes? How the nodes are distributed in the environment? What is the size of the network we plan to simulate, these questions (and more) are yet to be investigated and answered in this work?

1.2 Literature Review

The literature includes several works on simulating VANET networks. The authors in [3] simulate and assess the overall performance of a VANET network. The study aimed at optimizing the selection of the best possible routing protocol for providing reliability to data packet dissemination in an efficient way. The impact and effectiveness of the existing topology-based routing protocol for the VANETs application have been evaluated using the NetSim software tool. The results showed that a combination of a proper channel model together with an efficient routing protocol enhanced the link throughput of the VANET for fixed network size. Further, performance evaluation also demonstrated the impact of network sizes and routing protocols on packet loss, packet delivery ratio, average end-to-end delay, and overhead transmission. Another performed in [7] provided some recommendations for simulating what is called the Internet of Vehicles (IoV). They described their main features and the challenges of simulating them for specific purposes.

Other works in the literature tried to provide an overview of the current research state, challenges, and potentials of VANETs, as well as the way forward to achieving the long, awaited ITS such as the work of [2],[3], and [8]. On the other hand, some researchers studied the feasibility of using alternative technologies for vehicular network models [9]. In addition, a detailed description of the mobility management in a vehicular network was argued in [9]. The selection of the optimal routing protocol in VANET and simulating them is considered a challenging task. These issues were discussed in many research articles in the literature such as [7], [10], and [11]. Other works in the literature investigated a variety of issues in such networks. For instance, tracking dynamic nodes in a dynamic environment [12][13], and tracking mobile objects in health-related applications [14][15].

1.3 Problem Statement

Based on the literature, it is needed to perform experiments that can support network developers in designing efficient VANET networks in the Internet of Things (IoT) and smart cities. Also, there is a need to clearly define the requirements for simulating VANET networks. For instance, there is a severe lack of defining all the requirements that can make it clear when simulating a real environment that includes a VANET network. Therefore, in this work, the detailed requirements of simulating VANET networks are defined for the IoT and smart cities. Moreover, a series of experiments on VANET networks is performed aiming to determine the appropriate requirements that lead to minimizing the consumption of VANET resources under two communication technologies Wi-Fi 5 and Wi-Fi 6.

The rest of this article is organized as follows: Section 2 presents the research method followed in this work. Section 3 shows the obtained results of the experiments. Finally, the work is concluded in Section 4.

2. Research Method

2.1 Setting up the experiments

The simulator used in this work was a multiagent simulator developed using Java. The settings of the simulator were as follows:

- The simulation environment of 20x20 Kilometers.
- The technologies used in communicating the nodes were Wi-Fi 5 and Wi-Fi 6.
- The velocity of the nodes in the environment was fixed.
- The communication type is peer-peer based.
- A pair of nodes is considered communicated if and only if they are both in the communication range of each other.

- The routing protocols used in the simulations were "Probabilistic Flooding Routing" and "Binary Spray & Wait Routing".
- Each node in the environment was able to track other nodes in the environment.
- A message was randomly deployed in the environment. This message is called "Event" that was used to evaluate the methods used in this work.
- Each node move based on a particular mobility model.
- The experiments were carried out in different sizes.
- The simulations stopped when the Event was reported by the sink node.

In this work, we designed 72 experiments and for each experiment, we varied the parameters. Table 1 summarizes the experiments performed in this work. Each experiment represented a combination of the items in Table 2. This gives our work a wider view of the performance and the results and eventually provides a better recommendation to researchers.

The hardware specifications used to perform the simulations were as follows:

- Processor: Intel(R) Core (TM)2 Duo CPU T6600 @ 2.20GHz
- RAM: 4.00 GB
- Operating System: Windows 32-bit, x64-based processor

Table 2: Experiments parameters and settings.

# Of nodes (Network Size)	Routing protocols	Node's deployment strategy	Mobility mode used
- 1000 - 2000 - 3000	- Probabilistic Flooding Routing Protocol [16] - Binary Spray & Wait Routing Protocol [17]	- Gaussian Distribution - Uniform Distribution	- Rayleigh Model [18] - Cauchy Flight Model [19] - Levy Flight Model [20]

2.2 Benchmarking Methods

The benchmarking method followed in this work was based on using three main metrics as follows:

- The percentage of spreading: it shows the percentage of nodes in the environment (the whole environment) that get the "event" message.
- Number of messages: reflects the actual number of exchanged messages in the environment.
- Number of Steps: this metric measures the number of steps required to reach the stopping condition. In other words, it shows the speed of the experiment to complete the simulation.

Each experiment was run 10 times, then we considered their average aiming to have accurate results. Also, since we are dealing with a dynamic network, it was necessary to have this number of runs for each experiment. For instance, when the simulator deployed the node, it gives a position to each node that is different if we repeat the same experiment.

3. Results and Discussions

In the previous section, all the experiments performed in this work were described. Tables 3 to 6 present the experimental results of the Wi-Fi 5, while Tables 7 to 10 present the results of using Wi-Fi 6.

Our policy in analyzing the results was based on the following:

"The best performance covers more areas in the environment with a smaller number of messages and fewer steps"

When applying the obtained results to the above statement to Tables 3 to 6 for Wi-Fi 5, it can be observed that

better performance was obtained when having "Gaussian Distribution", "Rayleigh" mobility model, and "Probabilistic Flooding" routing protocol. This is because the experiments that use these two options provide the highest coverage areas with less consumption of network resources. Similarly, for the experiments shown in Tables 7 to 10 for Wi-Fi 6, we observed similar behavior. This means the aforementioned options work better in the simulations. Moreover, it is clear that Wi-Fi 6 significantly outperformed Wi-Fi 5 in terms of the number of steps required to cover more areas in the environment, which is expected.

Furthermore, as our goal in this work is to show the main requirements of simulating a VANET network, we show all the details required to simulate VANET environments as well as provide colorful experiments that we believe are of interest to network architects and developers. We also believe that these results are not our main focus in this work but they can be of interest to smart city developers.

TABLE 3: Wi-Fi 5 - Gaussian Distribution of Nodes/Probabilistic Flooding Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
1	1000	Rayleigh	84.156	839.4	993
2	1000	Cauchy Flight	80.918	804	521.8
3	1000	Levy Flight	82.24	815.8	356.6
4	2000	Rayleigh	77.49	1547.2	635.2
5	2000	Cauchy Flight	78.85	1570.6	338.6
6	2000	Levy Flight	73.104	1456.4	186.8
7	3000	Rayleigh	80.708	2418.6	405.2
8	3000	Cauchy Flight	72.744	2176.2	239.6
9	3000	Levy Flight	65.278	1951.4	136

TABLE 4: Wi-Fi 5 - Uniform Distribution of Nodes/Probabilistic Flooding Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
10	1000	Rayleigh	64.016	633.6	1518.2
11	1000	Cauchy Flight	47.374	469.4	644
12	1000	Levy Flight	71.75	712	307.8
13	2000	Rayleigh	71.484	1419.4	1052
14	2000	Cauchy Flight	67.396	1343.8	348.8
15	2000	Levy Flight	62.112	1236	179.4
16	3000	Rayleigh	69.622	2086.4	707.8
17	3000	Cauchy Flight	54.176	1621.6	223.8
18	3000	Levy Flight	78.934	2363	160

TABLE 5: Wi-Fi 5 - Gaussian Distribution of Nodes/Binary Spray and Wait Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
19	1000	Rayleigh	20.51	183.2	5627.6
20	1000	Cauchy Flight	15.886	142.2	1497.6
21	1000	Levy Flight	23.116	206.2	893
22	2000	Rayleigh	16.11	288.8	5442.4
23	2000	Cauchy Flight	14.07	252.6	1533
24	2000	Levy Flight	15.56	278.6	623.6
25	3000	Rayleigh	17.062	459.4	6427.6
26	3000	Cauchy Flight	11.656	313.8	1355

27	3000	Levy Flight	10.312	276.4	433

TABLE 6: Wi-Fi 5 - Uniform Distribution of Nodes/Binary Spray and Wait Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
28	1000	Rayleigh	22.178	198.6	9114
29	1000	Cauchy Flight	16.004	142	1857
30	1000	Levy Flight	13.908	124.4	578.8
31	2000	Rayleigh	17.68	317.8	7091
32	2000	Cauchy Flight	10.552	188.8	1159.5
33	2000	Levy Flight	11.45	206.8	544
34	3000	Rayleigh	13.576	365.8	6526
35	3000	Cauchy Flight	10.844	295.2	1292
36	3000	Levy Flight	8.91	242.8	401.2

TABLE 7: Wi-Fi 6 - Gaussian Distribution of Nodes/Probabilistic Flooding Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
37	1000	Rayleigh	78.84	787.2	40
38	1000	Cauchy Flight	80.478	802.6	35.4
39	1000	Levy Flight	76.806	767.2	21.2
40	2000	Rayleigh	84.49	1688	9.8
41	2000	Cauchy Flight	79.63	1591	9.4
42	2000	Levy Flight	81.4	1626.2	8.6
43	3000	Rayleigh	80.56	2414.6	5.2
44	3000	Cauchy Flight	81.896	2457.4	4.8
45	3000	Levy Flight	82.98	2487.6	4.2

TABLE 8: Wi-Fi 6 - Uniform Distribution of Nodes/Probabilistic Flooding Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
46	1000	Rayleigh	82.078	821	147.6
47	1000	Cauchy Flight	77.65	631.8	77.8
48	1000	Levy Flight	65.714	546.2	59.4
49	2000	Rayleigh	73.552	1468.8	26.8
50	2000	Cauchy Flight	80.52	1608.6	30.6
51	2000	Levy Flight	66.396	1326.2	23
52	3000	Rayleigh	77.306	2316.8	15

53	3000	Cauchy Flight	77.65	2327.4	14.8
54	3000	Levy Flight	72.484	2172.4	13.8

TABLE 9: Wi-Fi 6 - Gaussian Distribution of Nodes/Binary Spray and Wait Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
55	1000	Rayleigh	23.198	208.4	4667.6
56	1000	Cauchy Flight	17.962	160.8	780.6
57	1000	Levy Flight	13.006	115.2	175.2
58	2000	Rayleigh	20.69	371.8	4145.6
59	2000	Cauchy Flight	11.444	205.2	429.4
60	2000	Levy Flight	12.354	221.4	191.6
61	3000	Rayleigh	17.728	478.4	3338
62	3000	Cauchy Flight	9.312	250.8	372.8
63	3000	Levy Flight	9.536	256.8	156.8

TABLE 10: Wi-Fi 6 - Uniform Distribution of Nodes/Binary Spray and Wait Routing

Exp.#	Nodes	Mobility Model	Spreading%	# of messages	# of Steps
64	1000	Rayleigh	19.8	177.4	4193
65	1000	Cauchy Flight	16.962	152	781.6
66	1000	Levy Flight	11.428	101.6	143.2
67	2000	Rayleigh	15.76	283.2	3492.8
68	2000	Cauchy Flight	10.476	187.6	401.4
69	2000	Levy Flight	9.714	173.8	149.2
70	3000	Rayleigh	16.328	440.2	4043.8
71	3000	Cauchy Flight	10.196	274	422.4
72	3000	Levy Flight	9.164	246.8	155.8

4. Conclusions

This work shows the requirements for simulating VANET networks. We focus on determining the main requirements to simulate VANET networks in terms of the distribution of nodes, the mobility model for describing the movement of nodes, and the routing protocols used to exchange messages among network nodes. We enrich readers with experiments that we believe can be of interest to network developers. The simulation results show interesting facts about the VANET networks and the best strategies to minimize the consumption of network resources. The experiments of this work considered two communication technologies among network nodes, namely, Wi-Fi 5 and Wi-Fi 6. In future work, we plan to extend the experiments to include more mobility models and more routing protocols as well as use more deployment strategies for nodes. We also plan to involve a larger size of the network and measure the performance under a variety of metrics.

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قياس أداء شبكة *(VANET)* تحت تقنيـة *(Wi-Fi 6)*

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الخلاصة:

تعد شبكات المركبات من الشبكات المتنقلة، حيث تكون العقد فيها متحركة ويمكن أن تغير مواقعها داخل بيئة معينة بمرور الوقت. يمكن توصيل هذه العقد في أي وقت وفقًا لإستراتيجية محددة مسبقًا. تتطلب محاكاة هذا النوع من الشبكات اهتماماً كبيراً بالعديد من التفاصيل. علاوة على ذلك، تفتقر أدبيات هذا المجال إلى الأعمال التي تصف متطلبات محاكاة مثل هذه الشبكات. لذلك، يحاول هذا العمل وصف متطلبات محاكاة شبكات المركبات ***(VANETs).*** علاوة على ذلك، فإن الهدف من هذا البحث هو تحديد متطلبات محاكاة شبكات المركبات من حيث توزيع المركبات وأنماط الحركة وبروتوكولات التوجيه المستخدمة. تُظهر نتائج المحاكاة حقائق مثيرة للاهتمام حول شبكات ***(VANETs)*** وأفضل الاستراتيجيات لتقليل استهلاك موارد الشبكة. أخيراً، يأخذ هذا العمل في الاعتبار تقنيتي اتصال بين عقد الشبكة وهما ***(Wi-Fi 5)*** و ***(Wi-Fi 6).***

الكلمات المفتاحية: شبكات المركبات، تقنية***(Wi-Fi 5)*** ، تقنية***(Wi-Fi 6)*** ، نماذج الحركة، متطلبات المحاكاة.