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VANET PERFORMANCE EVALUATION IN TERMS OF NODES DISTRIBUTION, MOBILITY MODELS, AND ROUTING PROTOCOLS

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Abstract. Nowadays, Vehicle Ad Hoc Networks (VANETs) have become a new trend and one of the most attractive areas of research. It has a wide range of applications such as smart cities and the Internet of Things (IoT). The main issue of the VANET networks is the limitation in network resources such as power, and memory. Moreover, since VANET nodes are dynamic and move over time, the connectivity of the networks is also considered an important issue. This paper designs experiments that reflect a variety of scenarios in VANET networks. Many issues and factors in VANET networks have also been investigated in this paper. There are many factors that affect the whole performance of VANET networks (i.e., mobility models, routing protocols, and things distribution) in terms of network resources. Therefore, this paper aims at testing different mobility models such as the Human Mobility model, Cauchy Flight Mobility model, and Correlated Directions Mobility model, and investigate their impact on the consumption of network resources under a particular routing protocol such as Spray and Wait routing protocol, Probabilistic Flooding routing protocol, and Epidemic routing protocol. In addition, testing different distributions such as Uniform distribution, Gaussian (Normal) distribution, and Power-Law distribution). The resources we plan to investigate are energy sources and the amount of data exchanged. In the designed experiments, each simulation includes a combination of a mobility model, nodes distribution, and a routing protocol. The findings showed that each mobility model, routing protocol, or distribution is effective in a particular application. As a result, it was found that determining the application of the VANET network is a crucial step before performing a simulation or designing a network.

Keywords: *VANET Networks, Mobility Models, Nodes Distributions, Routing Protocols*

1. Introduction

A Mobile Ad Hoc Network (MANET) is a collection of wireless devices called nodes that move within an environment [1]. These nodes can communicate with each other without a particular infrastructure. The carrier of the nodes can be any vehicle (i.e., cars, tracks, bicycles, etc.) as shown in Figure 1. Moreover, VANET nodes can exchange data through communication between nodes. The capability of nodes to communicate with each other depends on manufacturer features (i.e., battery, wireless range, memory, etc.). Two VANET nodes are considered communicated if they are in the communication range of each other at the same time. Also, MANET networks contain mobile nodes that change their positions over time. This makes it a challenging task when nodes exchange information [1], [2].

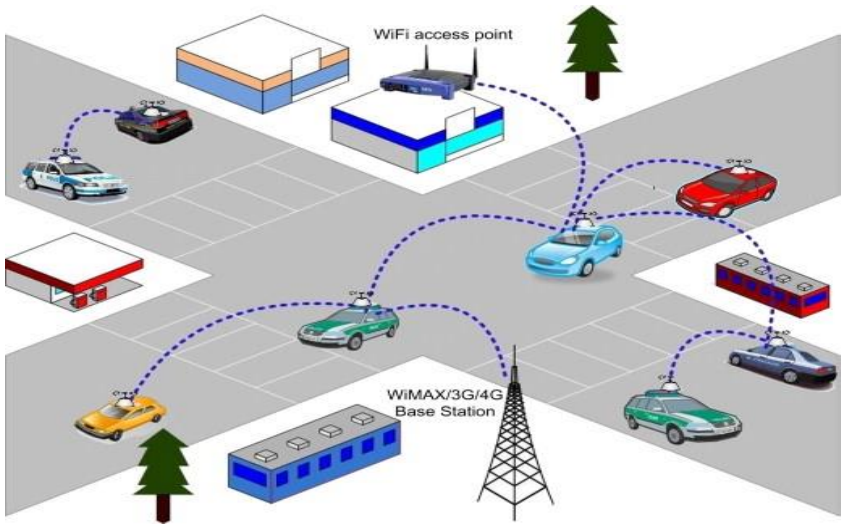

Figure 1: A typical VANET network.

Generally, there are many issues that should be considered by VANET architects as follows:
- Mobility: The mobility of nodes to move from one position to another is based on the mobility of the vehicle that carries the node. The trajectories of the nodes depend on the paths that these vehicles follow during movement [3].
- Privacy and Security: It is important to protect data from any unauthorized access [4].
- Power Consumption: The power of a node is one of the crucial factors that affect the whole network's performance [5].
- Memory Consumption: Receiving data from other nodes should be subject to some roles, otherwise the memory of nodes can face the issue of memory overflow [6].
- Routing: The method of sending data from one node to other nodes within the network should be completely governed by a particular strategy [7].
- Reliability: VANET networks may face a failure in the connection between two nodes or failure in a node itself due to damage or power-related issues. This causes a failure in sending and receiving data within the network [8].

Furthermore, the application and the purpose of a VANET network should be highly considered and given special attention by VANET architects.

The aim of this paper is to provide colorful experiments that include a variety of node distribution, mobility models, and routing protocols that can benefit VANET architects during the design phase. These experiments can contribute to enriching the knowledge of designers in providing recommendations for different VANET applications.

The main objectives of this paper can be as follows:
- Develop a simulator for the VANET networks that have the ability to simulate different scenarios of VANET networks.
- Design a series of scenarios that combine different distributions, mobility models, and routing protocols.
- Involve the parallel computing concept when performing the experiments.
- Measure the performance of the network in terms of the consumption of network resources (i.e., rate of exchanged data, coverage area, and data spreading percentage) using different metrics.
- Benchmark the designed scenarios and provide recommendations to VANET architects.
- Provide a platform that enables network architects to test a variety of scenarios before moving to real-world implementation.
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2. Research Methodology

In this paper, a wide range of experiments is designed for the purpose of carrying out and analyzing the VANET performance. The diversity of the settings and options gives the research a distinctive practical feature. In this type of experiment, it must be taken into account that the implementation of a particular experiment may not give the same results when the experiment is carried out again. The results may be close, but they are not completely identical, and for this reason, all experiments in this research were carried out on the basis that each experiment is carried out (10) times and then these trials are averaged and included in the data analysis. This method is considered practical and scientific because it expresses the behavior of a particular experiment by taking the rate of executing the same experiment many times. All experiments in this research include certain constants, such as the extent of communication. The adopted connection range is 50 meters, which is WiFi wireless technology. Also, in the experiments of this paper, we use only one event (i.e., a warning message) that is randomly spread within the environment. This event will be sensed by the VANET nodes and then transmitted to other nodes based on the routing protocol used. The number of experiments to be carried out is 450, each of which represents an average of 10 experiments under the same settings. The experiments are mainly divided into three groups, depending on the number of mobility models that were included in the experiments, which are three models. Therefore, tables were designed to summarize these experiments with all the settings used, as follows:

Group 1 (Cauchy Flight Mobility Model): Consists of 150 experiments and the implementation of the experiment was designed to stop when reaching 10000 steps. Table 1 includes all other settings for the first group of experiments. It appears from the table that there is a variety in the number of mobile nodes, the distribution density of nodes, the method of distributing mobile nodes, and finally the type of data routing protocol.

Group 2 (Correlated Directions Model): as shown in Table 2

Group 3 (Human Mobility Model): as shown in Table 3

Table 1: Group 1 experiments.

#	Density	No. of Nodes	Distribution	Routing Protocol
1	1.96, 2.94, 3.92, 4.9, 5.88	100, 200, 300, 400, 500	Power –law	Epidemic, Spray & Wait, Probabilistic Flooding
2	1.96, 2.94, 3.92, 4.9, 5.88	100, 200, 300, 400, 500	Uniform	Epidemic, Spray & Wait, Probabilistic Flooding
3	1.46, 2.44, 3.42, 4.4, 5.38	100, 200, 300, 400, 500	Normal	Epidemic, Spray & Wait, Probabilistic Flooding

Table 2: Group 2 experiments.

#	Density	No. of Nodes	Distribution	Routing Protocol
1	1.96, 2.94, 3.92, 4.9, 5.88	100, 200, 300, 400, 500	Power –law	Epidemic, Spray & Wait, Probabilistic Flooding
2	1.96, 2.94, 3.92, 4.9, 5.88	100, 200, 300, 400, 500	Uniform	Epidemic, Spray & Wait, Probabilistic Flooding
3	1.96, 2.94, 3.92, 4.9, 5.88	100, 200, 300, 400, 500	Normal	Epidemic, Spray & Wait, Probabilistic Flooding

Table 3: Group 3 experiments.

#	Density	No. of Nodes	Distribution	Routing Protocol
1	1.96, 2.94, 3.92, 4.9, 5.88	100, 200, 300, 400, 500	Power –law	Epidemic, Spray & Wait, Probabilistic Flooding
2	1.46, 2.44, 3.42, 4.4, 5.38	100, 200, 300, 400, 500	Uniform	Epidemic, Spray & Wait, Probabilistic Flooding
3	1.46, 2.44, 3.42, 4.4, 5.38	100, 200, 300, 400, 500	Normal	Epidemic, Spray & Wait, Probabilistic Flooding

3. Results and Discussions

3.1 Evaluating the Consumption of VANET resources

In order to reduce the waste of VANET resources, the overall performance of the consumption of resources should be maintained in terms of memory consumption, the amount of data exchanged, and the consumption of energy resources, which are among the most important challenges faced by VANET developers:

3.1.1 Data Exchanged

This part is considered one of the most important parts of the research because it reflects the consumption behavior of VANET network resources. In practice, the amount of data sent and received reflects the consumption of a group of resources at one time, as when a specific node sends or receives a specific message, the energy and memory resources of that node will be consumed as well as the consumption of data transmission path; Therefore, it is necessary to understand the data exchange processes between VANET network nodes.

Figure 2 reflects the behavior of the mobility models used (Correlated model, Human mobility model, and Cauchy Flight) using the Power-Law distribution for nodes with an Epidemic protocol for data transmission. In the figure, the X-axis represents the number of nodes used and a variable number has been used; For the purpose of observing the changes that occur in the event of an increase in the contract quantity 100, 200, 300, 400, and 500 nodes were used in all experiments. As for the Y axis, it includes the amount of data exchanged, which in turn represents the number of messages exchanged. In this figure, we note that the amount of data exchanged using the human movement model reaches its lowest level compared to the other two models. As a result of this superiority of the human mobility model, it is an important factor in determining the consumption of network resources, meaning that the adoption of the human mobility model should be taken into account by VANET developers.

Now, for the purpose of evaluating the results more accurately, the variations that occurred in the implementation of the experiments were investigated, and for this reason, we used a graphical statistical method called boxplot, which enables us to look at the data from another angle. Figure 3 depicts the changes that occur in the amount of data exchanged when the mobility models vary. In this figure, the X axis represents the mobility models used, and the Y axis represents the amount of data exchanged. We notice that the stability of the human mobility model slightly exceeds the stability of the other two models. In other words, the inclusion of the human movement model gives results that are more stable than the other models used.

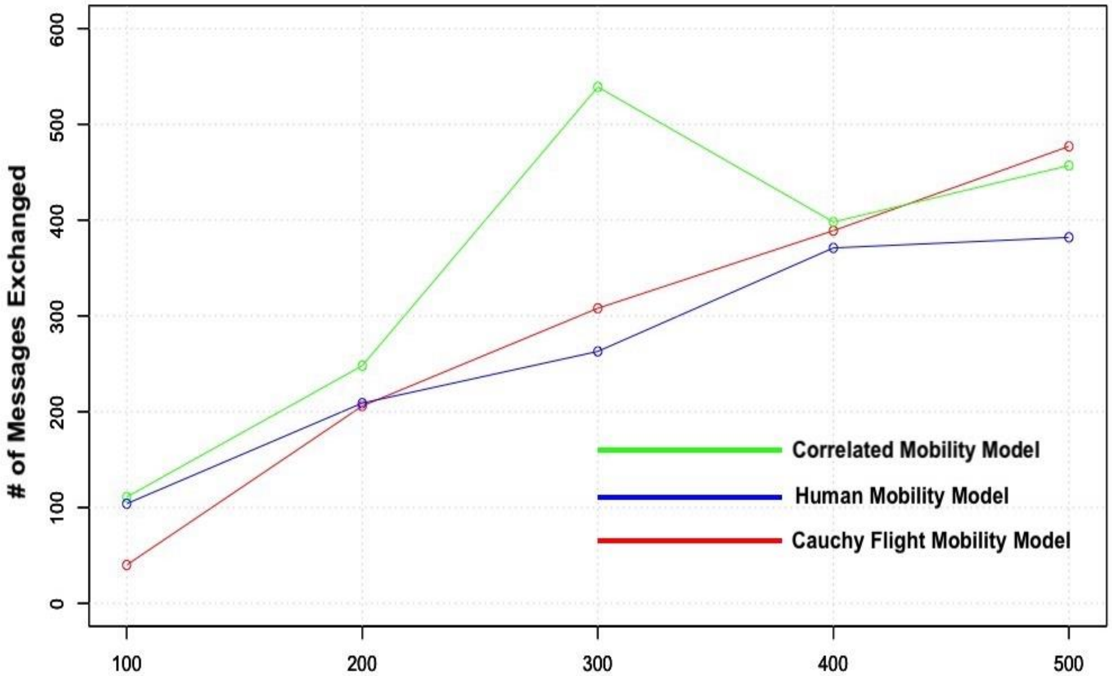

Figure 2: Amount of data exchanged for the three mobility models used with Epidemic routing protocol and Power-Law distribution of nodes.

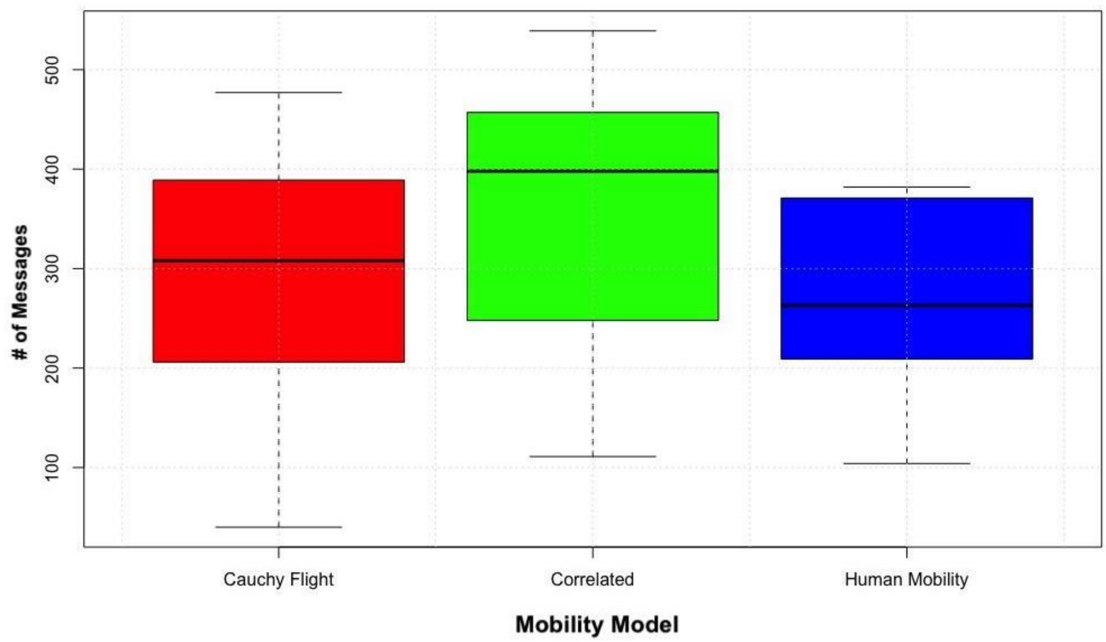

Figure 3: Variations of the mobility models when exchanging data under Epidemic routing protocol and Power-Law distribution of nodes.

The aforementioned experiments were conducted using the Epidemic routing protocol. Figure 4 reflects the implementation of experiments using the Spray & Wait algorithm to transmit data in the network. In this figure, the X-axis represents the number of nodes that we relied on the same method mentioned in the previous paragraphs. As for the Y axis, it represents the amount of data exchanged, and it is interesting in this figure that the Cauchy Flight model has a clear superiority over the rest of the models. We observed that the amount of data exchanged is at its lowest limit when using the aforementioned form. In terms of stability and variance in the amounts of data exchanged, the human movement model reflects higher stability and lower variance than the other two models. Figure 5 shows the variance in the three mobility models used. The figure also shows the emergence of an outlier value in the human movement model, which, after checking the data, turned out to be an extreme result of one of the experiments, and it was repeated only once. For such cases, each experiment was carried out ten times, and its rate was approved as a result of implementation.

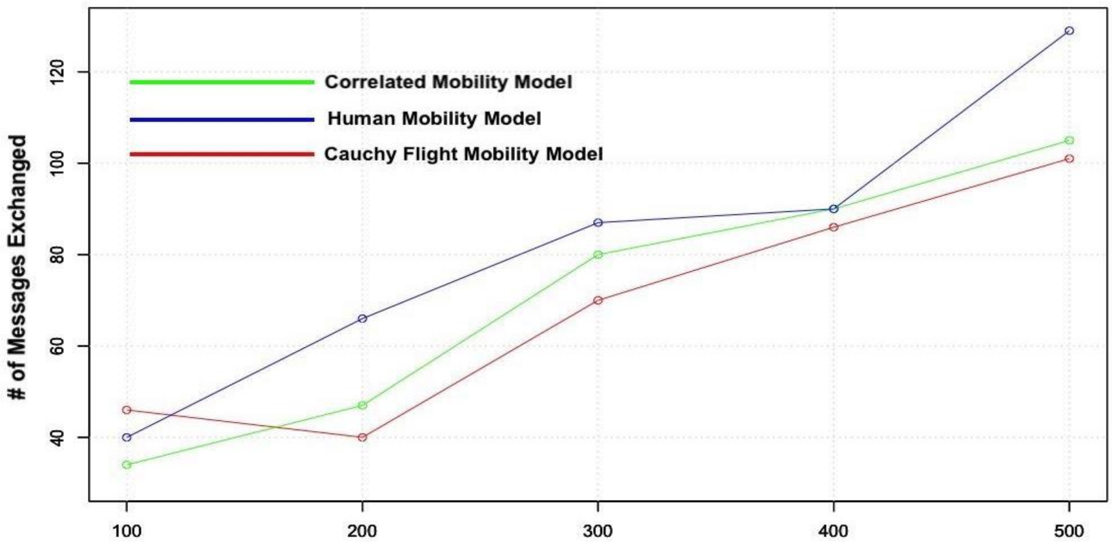

Figure 4: Amount of data exchanged for the three mobility models used with Spray & Wait routing protocol and Power-Law distribution of nodes.

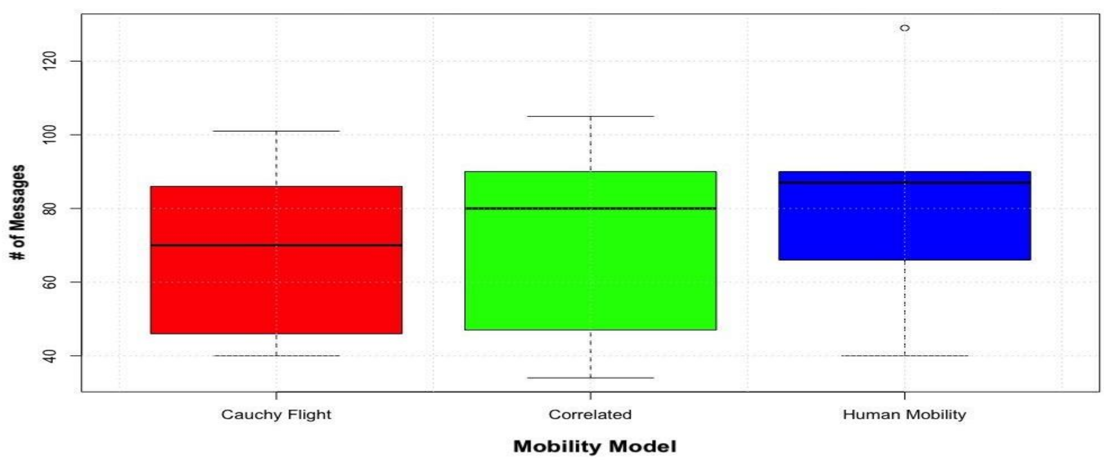

Figure 5: Variations of the mobility models when exchanging data under Spray & Wait routing protocol and Power-Law distribution of nodes.

We now come to analyze the results of the experiments after changing the routing protocol to Probabilistic Flooding. Figure 6 shows the amount of exchanged data for the three mobility models used, which clearly shows that the Cauchy Flight model outperforms the rest of the models used; Therefore, the use of this mobility model is effective by using the Probabilistic Flooding and Spray&Wait algorithms in data transmission, and it maintains the consumption of network resources.

On the other hand, there is a negative point in the performance of the Cauchy Flight model, which is the instability of the model and the variability of its results in various experiments. Figure 7 depicts the performance of the three mobility models, in which the fluctuation in the stability and variance of the amount of data exchanged is shown.

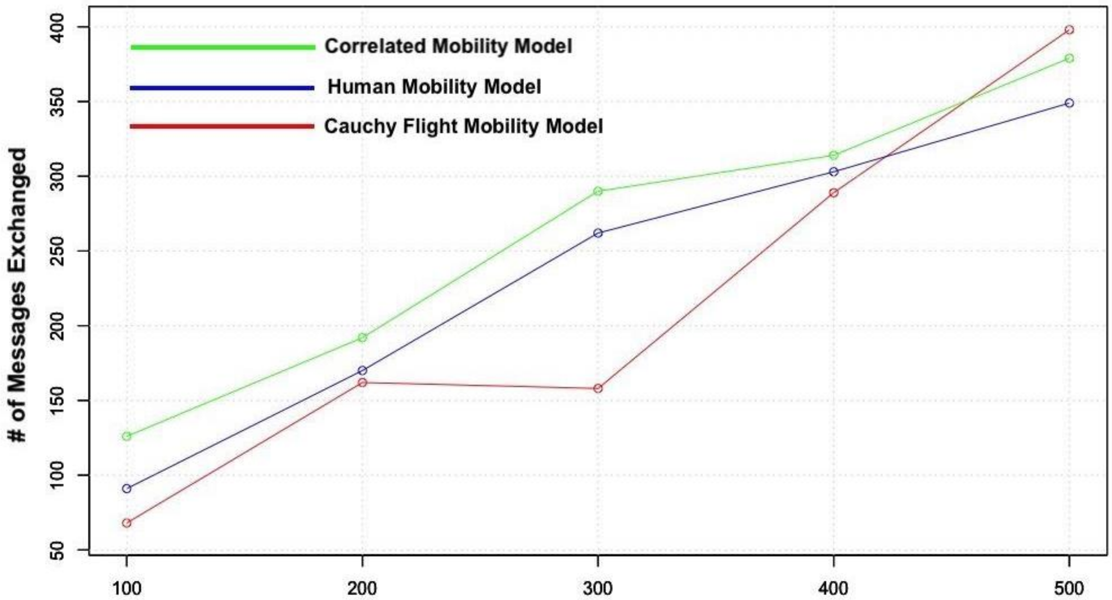

Figure 6: Amount of data exchanged for the three mobility models used with Probabilistic Flooding routing protocol and Power-Law distribution of nodes.

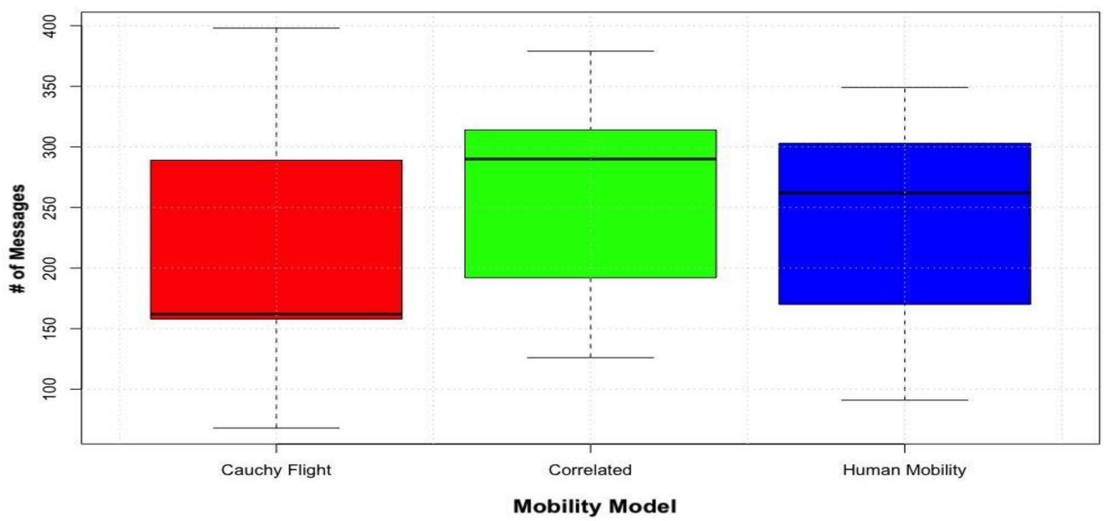

Figure 7: Variations of the mobility models when exchanging data under Probabilistic Flooding routing protocol and Power-Law distribution of nodes.

3.1.2 Power Consumption

Reducing energy consumption is one of the most important challenges that VANET architects struggle with because the nodes are mobile and do not have a continuous source of energy. Therefore, only the battery of these nodes is relied upon as a major source of energy. In fact, there are many factors that affect energy consumption, the most important of which is the amount of exchanged data that was explained in the above paragraphs. Now, we hypothesized that all nodes in the VANET. Also, all exchanged data is mainly obtained via Wi-Fi technology. Each process of sending or receiving data consumes a certain amount of energy from the battery which in turn is consumed by the Wi-Fi antenna which is one of the most power-consuming parts. Therefore, the less the amount of data exchanged, the lower the energy consumption is.

Here, it should be observed that reducing the amount of data exchanged should not be at the expense of the desired goal of network design. For example, when the goal is to deliver a specific message to a specific node in the network, this goal must be achieved and the message must be delivered to all intended nodes. Therefore, the goal is to achieve the network's objectives in terms of data transmission and to reduce or limit as much as possible the frequency of sending messages to the same node that leads to loss the energy in these iterations. Figure 8 shows the variation in the number of nodes that sensed the pervasive event in the network using the three mobility models adopted in this paper, and several routing protocols were used to transfer data (i.e., Epidemic, Spray & Wait, and Probabilistic Flooding). In the figure, we can observe that using the Correlated Directions mobility model with a Probabilistic Flooding routing protocol outperformed other models in terms of the number of nodes that received data (message or event). It can be seen that all the results obtained using the Epidemic routing protocol are not reliable because it is used only for benchmarking purposes.

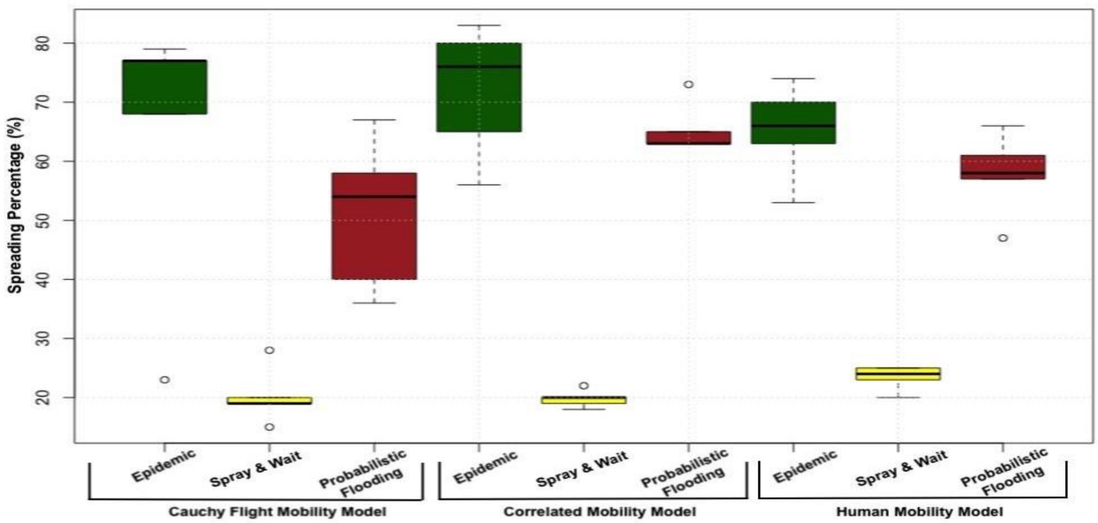

Figure 8: The percentage of the number of nodes that are covered data for all the mobility models used and all the routing protocols used.

3.1.3 Memory Consumption

Memory consumption is an important criterion in measuring the overall performance of the VANET network, and to clarify this issue, we assume the presence of a node that works on WiFi technology in data transmission. In this case, when the node is in a crowded area streets, such as a market, the number of nodes that are within range of this node is very large, in this case, if messages are received from the surrounding nodes or even sensing the surrounding Wi-Fis, the memory will be full in certain weeks; Therefore, the memory must be managed and the data that will be stored in should be determined, and the tendency is not to store non-valuable data for that node Wi-Fi. Figure 9 shows the performance of the three mobility models used and the three routing protocols as well. We observed from this figure that the Spray & Wait data routing protocol using the three mobility models reflects a small number of exchanged messages. The reason for this is that this protocol (as explained in the second chapter) passes data or messages in a very specific way, and this leads to reducing the consumption of VANET network resources in terms of memory and in other aspects such as energy consumption.

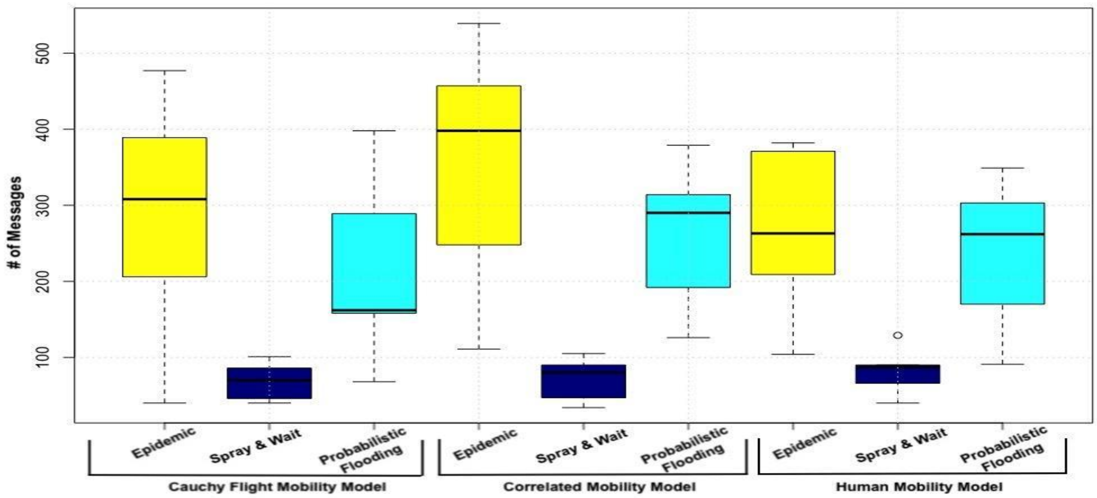

Figure 9: The percentage of the number of messages exchanged for all the mobility models used and all the routing protocols used.

3.1.4 Evaluating the Coverage area

One of the measurements used in this paper is the area covered by the data. Different mobility models were used with a variety of routing protocols aiming to show the optimal methods to cover the largest possible area with data. Figure 10 demonstrates the superiority of the Correlated Directions mobility model compared to the other two models when using an Epidemic routing protocol in terms of the area covered. We also observed that the human mobility model reflected a very close performance to the aforementioned model. The Cauchy Flight model lags significantly in its performance.

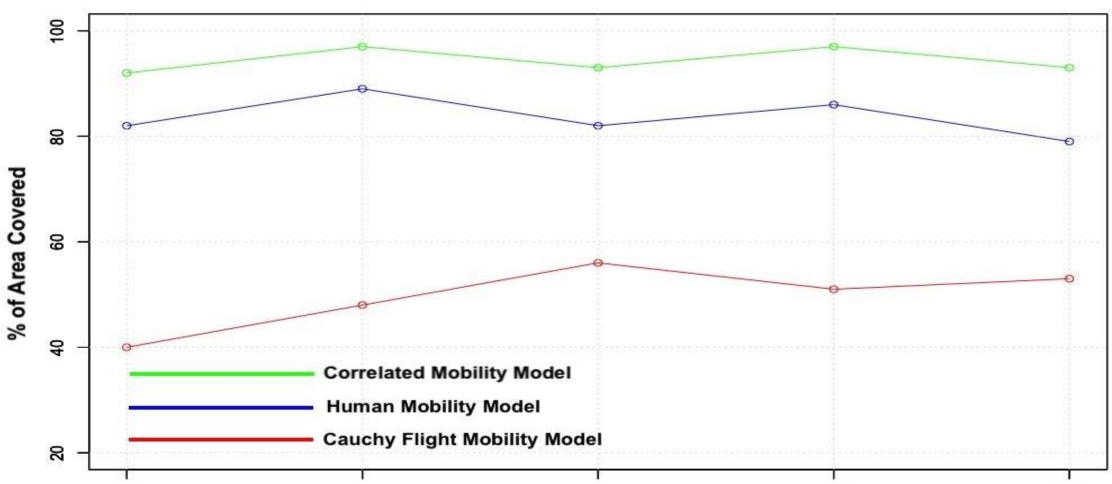

Figure 10: The area that is covered by data for the three mobility models used with Epidemic routing protocol and Power-Law distribution of nodes.

As for Figure 11, it reflects a result similar to the previous figure using the same previous settings, with the change of the transfer method to Spray & Wait, we noted a significant fluctuation in the performance of the Cauchy Flight model. This fluctuation is considered undesirable due to its instability, and it cannot be relied upon in this type of network, because the stability of the results of a particular experiment is an important matter in expressing the extent of its reliability.

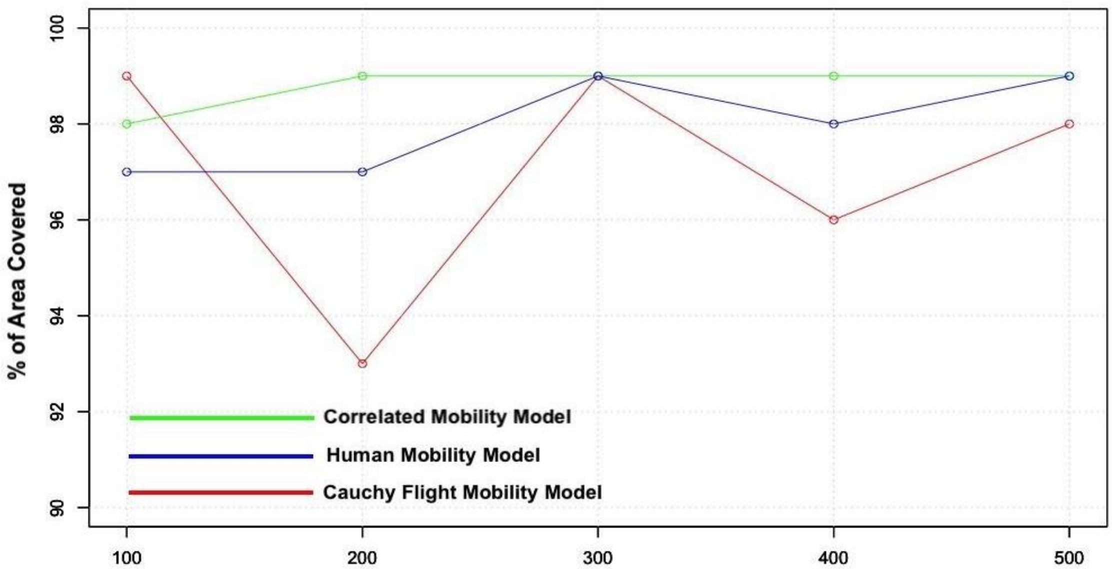

Figure 11: The area that is covered by data for the three mobility models used with Spray & Wait routing protocol and Power-Law distribution of nodes.

In Figure 12, the routing protocol was changed to Probabilistic Flooding, which in turn improved the performance of the Cauchy Flight model to outperform the Human Mobility model in the size of the area that is covered by data. As for the Correlated motion model, it remained superior in its performance to the rest of the mobility models used in this paper.

In the previous three figures, it was found that the Correlated Directions mobility model is one of the best mobility models that have the ability to cover the largest possible area with data in the network. This result is stable even when changing the routing protocols. This result is interesting because if the target is in the network at a certain time, it is possible to rely on the nodes that follow this model in their movement in spreading data to the largest possible areas in the VANET network.

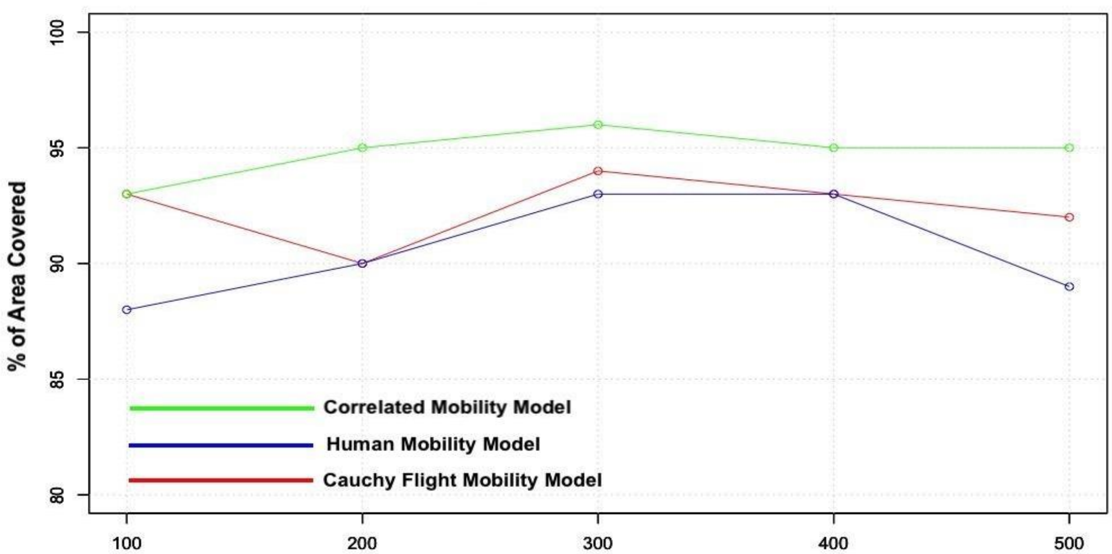

Figure 12: The area that is covered by data for the three mobility models used with Probabilistic Flooding routing protocol and Power-Law distribution of nodes.

3.2 EVALUATING THE NODES AFFECTED BY THE EVENT

In this section, the proportions of nodes affected by the event (message or alerts transmitted through the network) were measured. The nodes affected by the event are the nodes that sensed or received a specific event from other nodes. The same basis was measured as in the previous measurements. The settings were distributed in terms of the mobility model used and the routing protocols.

Figures 13, 14, and 15 show the performance of the three models used in this paper and the three routing protocols as well. We notice in these figures that the routing protocols are the main factor that plays the main role in determining the percentage of nodes affected by the event and that the mobility model has the same effect but in a second degree. In the above-mentioned three figures, we note that the best performance can be obtained using the Probabilistic Flooding method in data transmission with the Correlated traffic model because the Epidemic routing method is used for comparison purposes only.

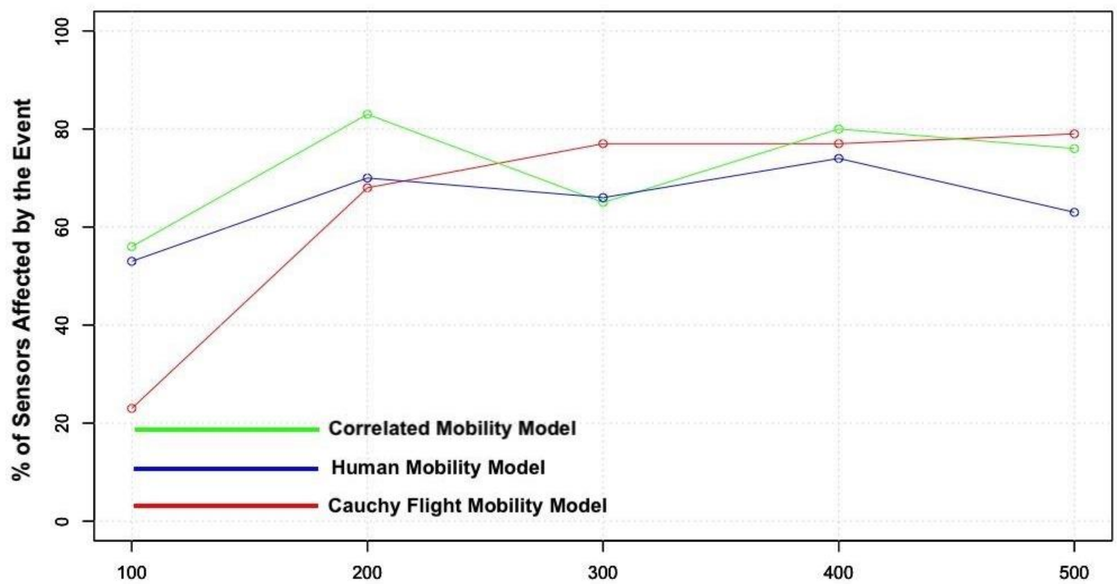

Figure 13: The percentage of the number of nodes that are affected by the event using the three mobility models used with the Epidemic routing protocol.

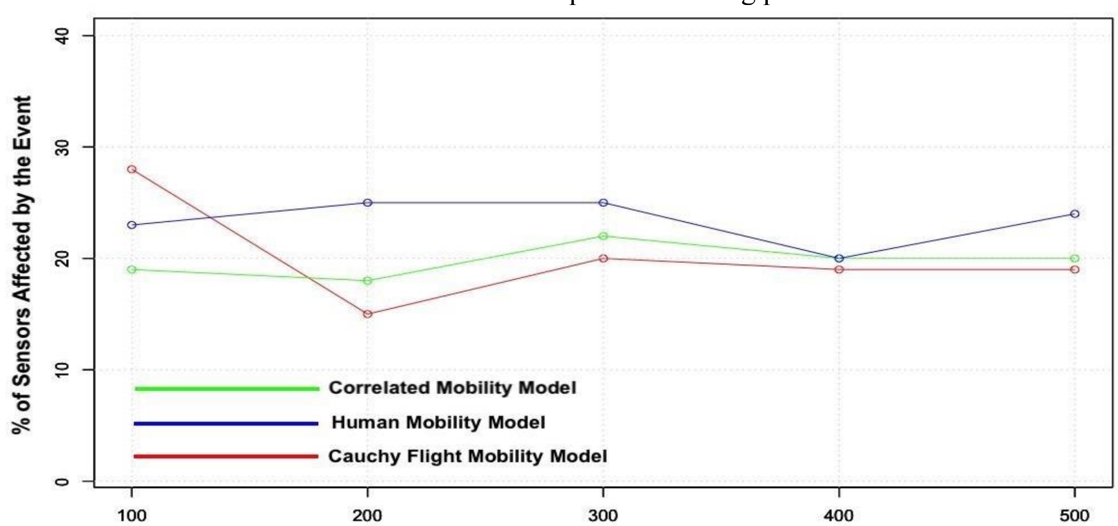

Figure 14: The percentage of the number of nodes that are affected by the event using the three mobility models used with the Spray & Wait routing protocol.

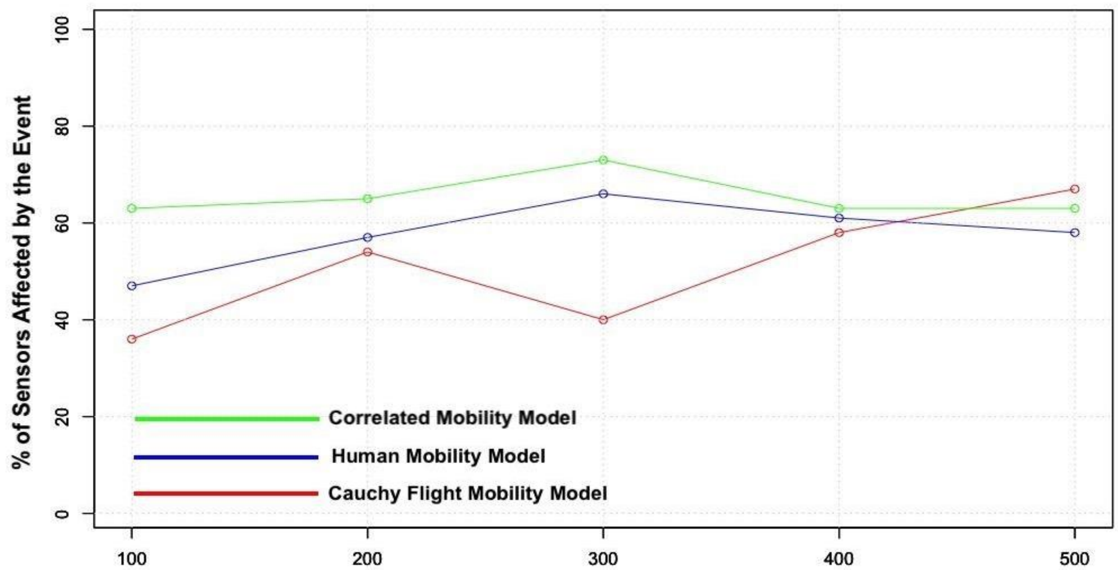

Figure 15: The percentage of the number of nodes that are affected by the event using the three mobility models used with the Spray & Wait routing protocol.

3.3 CONCLUSION

As described in the previous chapters, we simulated a VANET network with colorful scenarios that include different deployment strategies of nodes within the environment, different mobility models, and different routing protocols. The mobility models used were three; Human Mobility Model, Correlated Model, and Cauchy Flight Model. The distributions were; Power-Law, Uniform, and Gaussian. The routing protocols used were; Epidemic, Spray & Wait, and Probabilistic Flooding. A total of 450 experiments were designed and carried out, each representing a combination of the aforementioned variables. The purpose of the diversity of experiments is to demonstrate the effect of mobility models on the consumption of network resources. Many performance evaluation metrics were used in this paper, including the amount of data exchanged, the consumption of energy resources, and the consumption of memory. Other measurements were taken such as the coverage area and the percentage of nodes that are affected by an event in the network. We conclude that simulating VANET networks is challenging especially with a large number of variations in each experiment. Therefore, it is needed to accurately determine the application and purpose of the VANET network before designing experiments and performing simulations.

Finally, one of the future works that can be done in simulating VANET networks is to use more routing protocols and mobility models for the same experiment aiming to reflect a real-world situation. The mentioned proposals are applicable for future work, especially with the availability of software tools and applications that enable us to simulate VANET networks.

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