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Mobility Models as a Key-Performance Factor for Wireless Networks

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Abstract. Nodes in wireless networks can be static or dynamic. Static nodes are stationary and their positions are fixed and their distribution may follow a particular topology. On the other hand, dynamic nodes are considered mobile and their positions changed over time due to following a specific pattern of movement, which also lead to the concept of the topology being irrelated. Simulating such networks needs a lot of attention and many requirements should be held. For instance, nodes in dynamic wireless networks are distributed according to a distribution that reflects the nature of the environment (e.g., Gaussian, Power-Law, Uniform distribution, etc.). Moreover, describing the movement patterns of nodes in dynamic wireless networks need to follow a particular mobility model that describes the movements of nodes in terms of speed and direction (e.g., Individual mobility model, Levy Flight Model, Cauchy Model). In addition to the aforementioned requirements, it is needed to incorporate a routing protocol that governs data spread within the simulation environment. This work designed a variety of experiments that combine the mentioned requirements and measure the performance of dynamic wireless networks under colorful settings and configurations. The metrics used in this approach are the amount of data exchanged, coverage area, and power and memory consumption. Mobility models, node deployment strategy (distributions), and routing protocols are the three factors that will be involved in the experiments. The experiments deal with four mobility models Random Way Point Mobility Model (RWPM), Street Random Way Point Mobility Model (SRWPM), Manhattan Mobility Model (MM), and Levy Flight Mobility Model (LFM). Three distribution models will be used in the experiments Power-Law Distribution, Chi-Squared Distribution, and Normal Distribution. The third factor that will be involved in the routing protocol, is Probabilistic Flooding Routing Protocol. Different experiments are benchmarked using these metrics. The results of this work will reveal facts about dynamic network simulations and provide some recommendations to network developers and architects.

Keywords. Wireless Networks, Mobility Models, Nodes Distribution, Routing Protocols.

1. Introduction

1.1 Background

Wireless technologies (e.g., Wi-Fi or Bluetooth) enable more than one device to be connected remotely. These technologies can be embedded into a variety of devices such as smartphones, laptops, printers, smartwatches, etc. Moreover, wireless technologies make it easy for devices not only to be connected to the same network's devices but also to remote networks' devices through the Internet. The currently available wireless technologies have the ability to connect stationary and mobile devices [1].

The performance of a wireless network can be analyzed in three different ways using test-beds, using simulations, or using analytical methods. So there is a tradeoff between which method is used and with respect to accuracy and convenience. Test-bed based methods are the least convenient and the analytical methods are the most convenient. In terms of accuracy on the other hand test-bed based is the best method that would lead to the most accurate results of the performance compared to the simulation-based means and the analytical based means. In terms of convenience analytical models are the most convenient because we are talking about designing mathematical models and mathematical equations which are easier to perform compared to simulations running. Capturing the real scenario of the movements in test-bed based methods is considered the most difficult one.

In this research, we will use simulation to measure the performance of wireless networks, taking into consideration four factors: mobility models, node distribution models, routing protocols, as well as the velocity of nodes.

Mobility Models are a method of simulating the movement of mobile nodes. The mobility models are classified into three different types: Stochastic models, Hybrid Models, and detailed Models. In terms of realism, the stochastic models are the least realistic on the other hand the detailed models are the most realistic. The higher the realism, the better the mobility models' ability to predict the performance of the network system in a real scenario. In terms of diversification stochastic is the easiest to diversify, then come to the hybrid models, the most difficult ones to diversify are the detailed models. The diversification quantifies the ability of a model to diversify to a large number of different scenarios, including different types of mobile nodes and different types of environments. In terms of complexity, the complexity is the least in the stochastic models whereas the most complexity is in the detailed models. Complexity is the measure of the computation resources required to produce the traces of the simulation. In this paper, Four types of motion models that we will use in the experiments

- Random Way Point Mobility Model (RWPM) [2]
- Street Random Way Point Mobility Model (SRWPM) [3]
- Manhattan Mobility Model (MM) [4]
- Levy Flight Mobility Model (LFM) [5]

The second factor that has a clear impact on measuring the performance of a wireless network is the method of distributing nodes [6]. There are several methods for distributing nodes such as normal distribution, exponential distribution, chi distribution, regular distribution, Power Law (long-tail) distribution ... etc. Whereas the third factor is the use of a particular routing protocol. The process of routing or transferring data from one party to another is not random, but rather is subject to norms or so-called protocols, and these protocols are designed according to the needs of the network or the system in which it operates. There are many protocols designed by developers to fit with all Requirements, such as **Epidemic Protocol [7]**, **Probabilistic Flooding Protocol** [8], **Spray and Wait Protocol** [9], etc.

1.2 State of the art

The simulations of dynamic networks have been widely considered in the literature. The main attraction point behind this tendency is that dynamic networks are highly related to the backbone structure of the Internet of Things (IoT) and smart cities. This kind of simulation is important insofar as it enriches network architects with knowledge about several issues such as connectivity, resource consumption, coverage area, and security, to mention but a few. Our key-performance scope in this research is on the works that are concerned with coverage area and the amount of data exchanged, which significantly contributes to the overall performance of a network. One of the studies performed by Tomasini et al. [10] incorporated a random mobility model (e.g., Individual Mobility) into a dynamic opportunistic network. Their goal was to assess the performance of the network in terms of the areas that can be covered. Their results showed interesting facts about simulating such networks as well as the potential improvements in the design. In the same context, another work performed by Mahmood and Menezes [11] used a variety of mobility models aiming at evaluating the performance of a mobile network in terms of memory consumption. They suggested that node relations and interactions can be considered powerful tools when it comes to designing models that minimize the consumption of network resources. Furthermore, considering the mobility patterns of people enables researchers in estimating the impact of particular phenomena (e.g., health-related phenomena) on the whole network environment. For instance, several works in the literature have investigated the dissemination of covid-19 within an environment based on the movements of people. The work of Hernandez and Martinez [12] demonstrated that mobility models can help us in understanding the temporal risk of covid spreading within public areas. The study also showed that the simulations may support health authorities in designing effective risk management strategies during epidemics. Similar studies have been published in the literature such as [13, 14,15].

1.3 Problem Statement and Research Contribution

According to the literature, it can be observed that most of the works have not considered the relationship among factors when simulating networks such as the relation between mobility models used and other factors. The other lack in the literature is that the majority of research articles in this area have missed involving some important factors such as nodes deployment strategies. This issue can be considered a severe lack in the literature insofar as it directly affects the overall performance of the network in terms of resource consumption and other metrics. Hence, this work comes to fill this gap and develops colorful experiments that combine different factors and evaluate the performance in terms of two metrics, namely, coverage area and amount of data exchanged. This work is important since the results will be used to reveal many facts about network performance under a variety of factors. Also, the results can be of interest to network architects since many recommendations will be provided.
The rest of this article is organized as follows: the next section introduces the research method followed in this work. It also describes the experiments performed in this work. Section 3 demonstrated the experiment results and discusses them. Finally, this work is concluded in Section 4.

2. Research Method

The first step in this research is designing experiments using different factors and parameters. Three factors were involved in the experiments, Mobility models, node deployment strategy (distributions), and routing protocols.
For the mobility models, four models were used as follows:

- Levy Flight Mobility Model (LFM)
- Manhattan Mobility Model (MM)
- Street Random Way Point Mobility Model (SRWPM
- Random Way Point Mobility Model (RWPM)

The distributions used in the experiments were three:

- Power-Law Distribution
- Chi-Squared Distribution
- Normal Distribution

The third factor involved was the routing protocol, which was Probabilistic Flooding Routing Protocol.
The strategy followed in designing the experiments was based on combining the aforementioned factors. Table 1 presents the proposed experiments and their main features.

Table 1: Experiments performed in this work

Experiment ID	Mobility Model	Distribution	Routing protocol	Node's velocity
1	Levy Flight	Power-Law	Probabilistic Flooding	12km/h
2		Chi-Squared		
3		Normal		
4	Manhattan	Power-Law	Probabilistic Flooding	35km/h
5		Chi-Squared		
6		Normal		
7	Street Random Way Point	Power-Law	Probabilistic Flooding	3km/h
8		Chi-Squared		
9		Normal		
10	Random Way Point	Power-Law	Probabilistic Flooding	3km/h
11		Chi-Squared		
12		Normal		

For the purpose of simulating the experiments, the SNoS model that is based on Net-Logo simulator is used. The SNoS is a multi-agent modeling simulator that is able to simulate different kinds of networks (i.e., static, dynamic, and hybrid). Many configurations were set in the simulator aiming to fit the purpose of this work. These configurations can be summarized as follows:

- The simulator environment was configured to be a squared environment of 5x5 km.
- The velocity of mobile nodes was assigned based on the mobility model used. The velocity of mobile nodes under the Levy Flight and Manhattan models was 3km/h, which is because these models are close in pattern to the human behavior in movement. In the Random Way Point model, the velocity of nodes was 12km/h that is because this model fits the case when involving, for instance, bicycles, motorcycles, or similar mobile objects. For the nodes in the Street Random Way Point model, the velocity used was 35km/h simulating the average speed of cars and automobile objects inside a city.
- The communication range of the nodes was 50 meters (Wi-Fi).
- The communication type is peer-to-peer-based.
- In the environment, a message was randomly positioned aiming to sense it by network nodes.
- All the experiments were executed 8 times for accuracy purposes. This is because one execution of an experiment may not reflect the actual performance due to the dynamic nature of the environment. Given that 12 experiments were designed and since 8 executions were performed for each experiment, the total number of executions was 96, which is believed to be sufficient enough to achieve the goal of this work.
- Two main metrics were mainly used in evaluating the performance. The first one is the Coverage Area, which is an indicator of the areas that are covered by the communication range of the nodes. This metric does not reflect the number of nodes affected (sensed) by the event. The second metric is the number of messages exchanged within the simulation environment. It can also be considered as an indicator of the power consumption level.
- The stability of the experiments was also evaluated for each mobility model involved in the experiments.

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3. Experimental Results and discussion

The experiments shown in Table 1 were implemented and their results were collected and, then, analyzed. The presentation of the results is based on the metrics considered; coverage area and the number of messages exchanged.

3.1. Coverage Area

The coverage area was tested under each mobility model used in this work. The experimental results were visualized separately considering two aspects *performance* and *stability*. The former reflects the areas that were covered under a particular experiment (see Table 1). The latter shows how stable the performance is.

Figure 1 depicts the performance of the experiments 1, 2, and 3 that include the Levy Flight as the mobility model and the Probabilistic Flooding as the routing protocol used, and both are implemented under three different distributions (Power-Law, Chi-Squared, and Normal). The figure shows that the experiments 1 to 3 work better when using the power-law distribution followed by Normal distribution, and then Chi-Squared distribution in all the 8 executions. The average performance, as shown on the most-right side of the figure, confirmed these results.

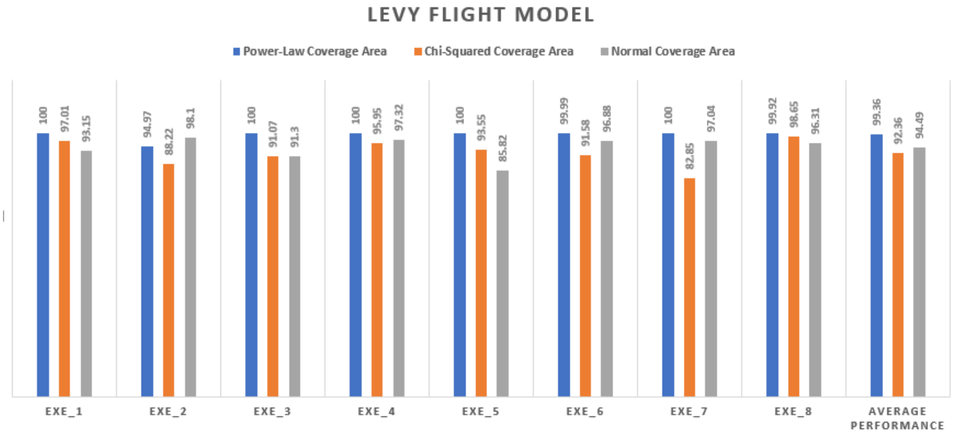

Figure 1: LFM coverage area performance under different distributions.

Figure 2 demonstrated the experimental results of the MANHATIN mobility model for the experiments 4, 5, and 6. Again, the performance of the power-law distribution outperformed the other distributions' performance. This result is interesting since it shows the ability of power-law distribution in covering more areas compared to the other distributions. However, it is needed to see the performance of the other mobility models under this distribution and track their behavior.

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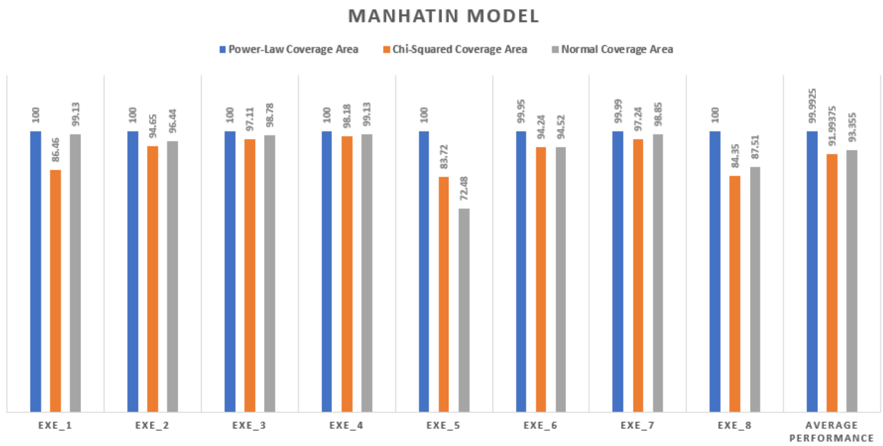

Figure 2: MM coverage area performance under different distributions.

The experiments 7, 8, and 9 were implemented using Street Random Way Point mobility model and the probabilistic Flooding Routing protocol under the three distributions. The figure shows that similar behavior was obtained when observing the covered areas under the power-law distribution. A close performance was gained under the Chi-Squared and Normal distributions. Similarly, the experiments 10, 11, and 12 for the Random Way Point mobility model provide the same behavior as shown in Figure 4.

These results led to one conclusion, which is all the mobility models used work better when the deployment of nodes follows a power-law distribution. The reason behind this phenomenon is that nodes under this distribution are concentrated and close to each other. Furthermore, the results show that MANHATIN mobility model reflected a better performance compared to other mobility models, which is due to the movement pattern nature that enables nodes to move with long jumps and cover more areas within the environment.

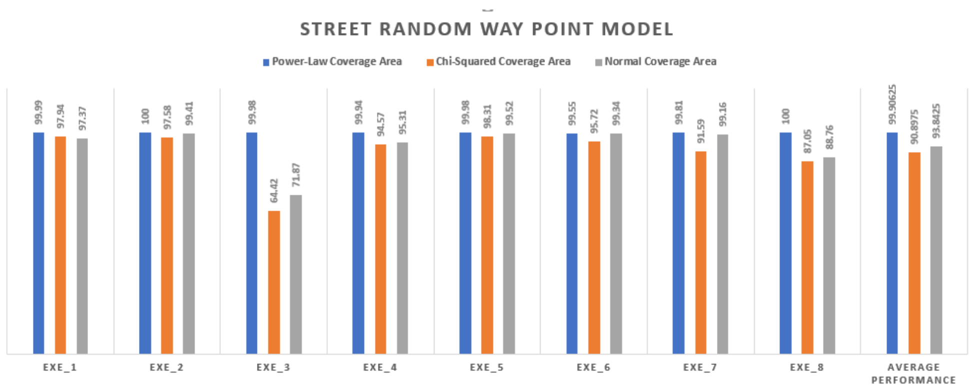

Figure 3: SRWPM coverage area performance under different distributions.

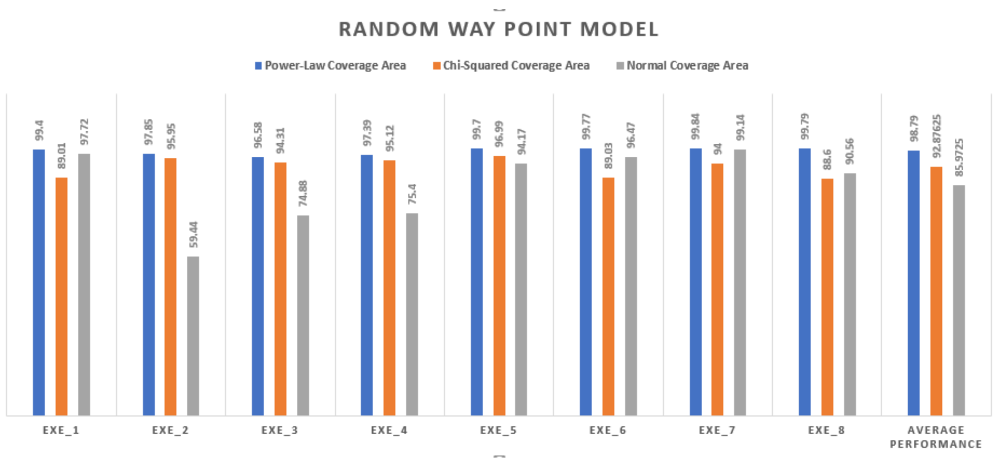

Figure 4: RWPM coverage area performance under different distributions.

3.2. Messages

The number of exchanged messages is another important indicator of the performance of the experiments. Based on the experiments in Table 1, a series of simulations were performed. For the experiments 1, 2, and 3, the performance is demonstrated in Figure 5. The figure shows eight executions for each experiment considering the Levy Flight mobility model with a routing strategy based on the Probabilistic Flooding routing protocol under the three distributions. The results reveal the poor performance of the experiments when deploying the nodes using power-law distribution. This can be interpreted as a side effect of the combination between the mobility model and the distribution. In other words, the power-law distribution concentrates the nodes in a particular area within the environment. Additionally, the Levy Flight model restricts the movements of nodes in a way that makes each node has many small jumps and fewer long jumps, which reduces the probability of a node meeting new nodes and eventually reduces the number of messages exchanged. However, this situation may be useful when the goal is reducing the consumption of network resources. It should be mentioned that each message exchanged consumes time, memory, and power. As can be observed in the figure, the performance normal distribution is significantly higher than the other distributions when using the Levy Flight model. The figure also shows the unstable behavior of the experiments when involving the Chi-Squared distribution, which can be seen when observing the results of the executions from 1 to 8.

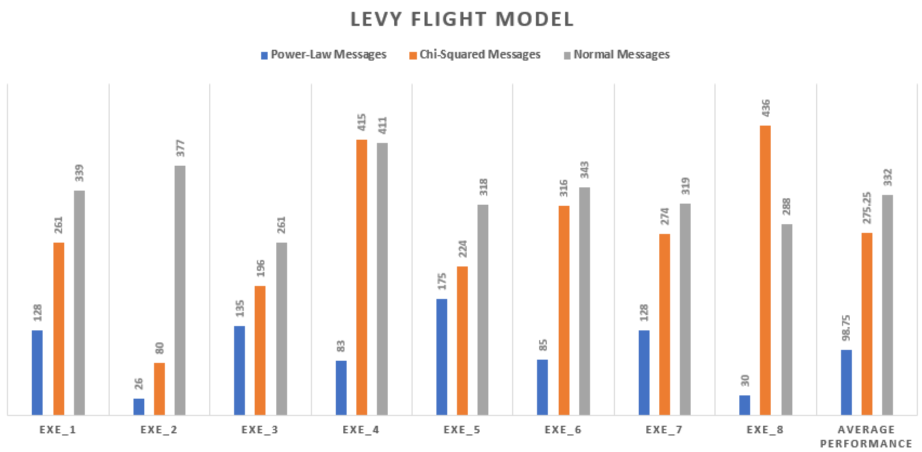

Figure 5: LFM messages exchanged performance under different distributions.

In Figure 6, a different behavior was obtained when using the experiments 4, 5, and 6. Since the use of MANHATIN mobility model forces nodes to move to more areas within the environment, the number of exchanged messages was high, especially when using the power-law distribution. However, the performance of the MANHATIN model reflected close behavior when varying the distributions.

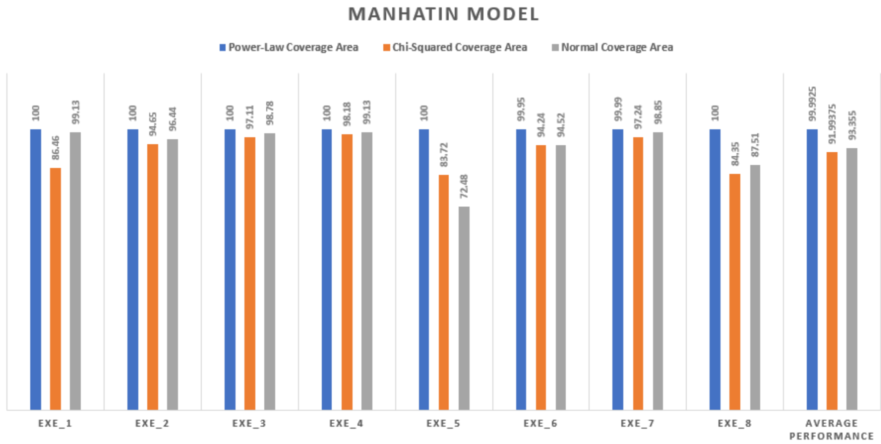

Figure 6: MM messages exchanged performance under different distributions.

The performance of the experiments 7, 8, and 9 is shown in Figure 7. It can be observed that the performance shows a behavior that is similar to the Levy Flight model with a high restriction on spreading messages. The results also show that Normal distribution reflected a high level of spreading messages. Similarly, the performance of the experiments 10, 11, and 12 (see Figure 8) shows the same behavior compared to the previous results in Figure 7.

According to the results, the performance varies when varying the parameters (e.g., mobility models and distributions). These results can be useful in some applications, while they are not feasible in other applications. For instance, if the goal of an application is to spread information to more areas, specific mobility should be used with some distribution. Also, when the goal is to spread more messages, a particular mobility model and distribution should be held.

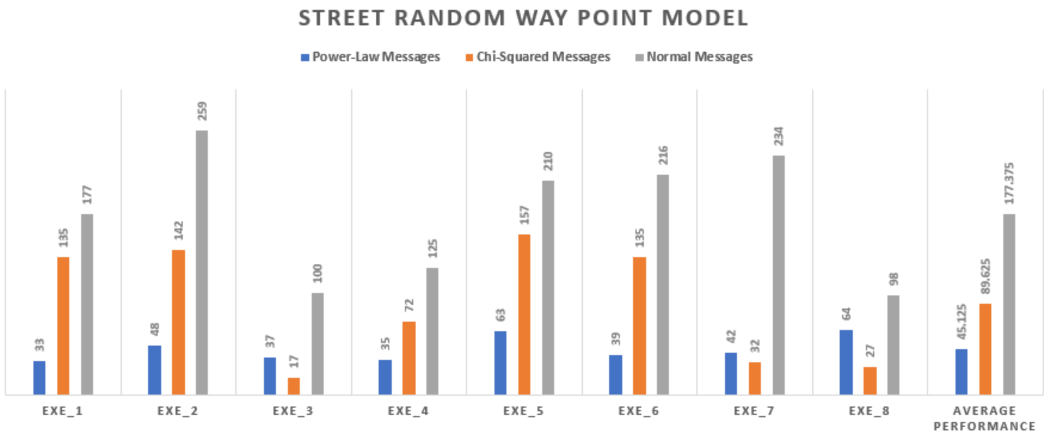

Figure 7: SRWPM messages exchanged performance under different distributions.

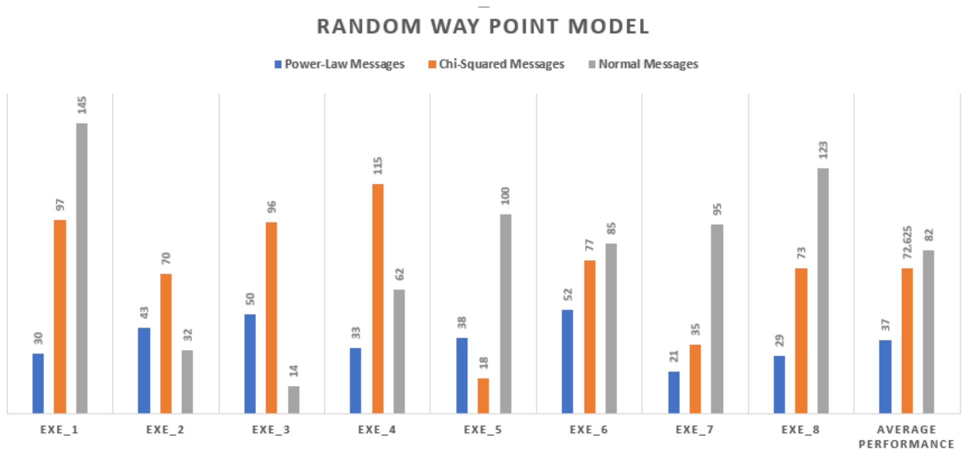

Figure 8: RWPM messages exchanged performance under different distributions.

4. Conclusions

This work performs a variety of experiments that combine four different mobility models (e.g., Levy Flight, MANHATIM, Street Random Way Point, and Random Way Point), three node distributions (e.g., Normal, Chi-Squared, and Power-Law), and the Probabilistic Flooding routing protocol. The combination of these parameters led to 96 experiments in four groups. Each experiment was executed for eight times aiming to have more accurate results and to show the stability of the performance. Two metrics were used to measure the performance namely, coverage area and the number of messages exchanged. The findings showed that some mobility models with a particular distribution can provide different results. Therefore, we concluded that mobility models play a crucial role in the performance of wireless sensor networks. The results confirmed this conclusion since some mobility models have the ability to cover more areas, while others can limit the spreading of information to fewer nodes within the simulation environment. As future work, it is planned to use more mobility models and routing protocols and perform experiments on different kinds of wireless networks aiming to compare the performance with the results of this work.

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