UAVNet Simulation in UAVSim: A Performance Evaluation and Enhancement

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Abstract. Several works have been done to design a simulation testbed for unmanned aerial vehicles (UAVs) in order to simulate the UAV Network (UAVNet) in a cost-effective manner. Our previously developed UAVSim is one of those attempts and has the capability of simulating large UAV networks as well while giving detailed results in terms of mobility modeling, traffic measurements, attack analysis, etc. The usefulness of such a simulation testbed cannot be guaranteed unless it is hardware independent. Therefore, we present a performance evaluation of such a recently developed software simulation testbed, UAVSim, using traditional and generic hardware available in any regular computer laboratory, in order to show its usefulness in an academic research setup. We show performances for two different environments for two separate machines. Results show that the simulation time is quite predictable and reasonable for a particular network size.

Keywords: Testbed Performance · Simulation Testbed · UAVNet Security

1 Introduction

The domain of UAVs has broadened due to its application in every field. Initially, the primary focus of development was Military in nature but real world civil applications are on a rapid increase. With industries like pizza delivery [1] and local package delivery [2] systems trying to use UAVs for their businesses, there are much more applications to come. Nonetheless, the importance of their use in the military domain has only increased in the recent past and the inclusion of civil UAVs in the national airspace is being delayed due to several issues including security [3].

As several UAV use related issues are being addressed, the need of a secure and safe UAV system can't be ignored for neither military nor civil applications. Due to this reason, several researchers have developed different kinds of simulation testbeds in order to validate proper functioning of these systems and verify their characteristics before deployment. Software simulation testbeds developed using Matlab/Simulink [4], FlightGear [5], JSBSim/FlightGear [6] and Matlab/FlightGear [7] are some of the examples. All these simulation testbeds are focused on testing a single UAV model instead of modeling its behavior in the real world scenario. Some other simulation

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testbeds using hardware along with software have also been developed where the hardware might be actual UAVs [8], [9], robots [10], [11], or just laptops [12], [13]. The only true software simulation testbed developed so far, called SPEEDES (Synchronous Parallel Environment for Emulation and Discrete Event Simulation) [14], simulates a swarm of UAVs on a high performance parallel computer so that it can match the actual speed and communication rate of the real UAVNet. Keeping all these important works focused on development of a simulation testbed for UAVs, we developed UAVSim.

The rest of the paper is organized to provide more details about UAVSim in Section 2 covering its design and features. Section 3 describes all the performance analysis done and related results and inferences. Section 4 concludes the paper and discusses possible future enhancements to the work.

2 UAVSim – Design and Features

As discussed in the previous Section, the focus of developing a simulation testbed has been simulating the behavior of a single UAV to check its working and proper functioning. Due to the use of a large number of UAVs nowadays, it is very much needed to judge the performance of these UAVs in a swarm of aircrafts when the authorities are talking about integrating UAVs in the National Airspace. Keeping all these requirements in mind, we initially worked on the UAV component level modeling, individual simulation, attack classification and attack modeling [15] and later developed a software simulation testbed called UAVSim for simulations of all sizes of UAV networks [16].

UAVSim is developed using the open source network simulator OMNeT++ and one of its independently developed open source modules called INET. The network design and higher level code is coded in NED, a language specifically designed for OMNeT++ while the lower level functioning is coded using C++ [17]. Although it has an in-built GUI and result analysis module, we developed most of the modules as per our requirement to make it more user-friendly.

One of the most important feature and primary focus of UAVSim is the security simulation of UAVNet. Several attacks have been implemented in the attack library of the testbed. Further, basic and advanced models of UAV have also been designed as well as the facility of using external models is provided. These external models are usually XML based and developed by other researchers. As mentioned earlier, the interactive GUI of UAVSim lets user vary various parameters while advanced users can directly manipulate the configuration files. Most performance tests were performed for security simulations and are reported in Section 3. Apart from supporting mobile wireless communication and UAV component level modeling capability, UAVSim also supports detailed network analysis at lower levels of the protocol stack. Further, attacks targeting different layers can also be designed, launched and tested in UAVSim. One of the most important features of UAVSim from user perspective is its user-friendly design and its ability to work on generic computing environment. Fig. 1 summarizes the important features and modules of UAVSim.

2.1 User-Friendly GUI Simulation

The simulation testbed supports both command line and graphical user interface. We have developed a custom GUI for UAVSim which lets basic users select possible options for some parameters. Users do not get a lot of independence in the basic GUI. While, the advanced users can edit all other parameters as well using the configuration file in the simulation project. The advanced user GUI is still under development and is expected to be finished soon. Although the GUI might cost some resource, it definitely can be counted as one of the performance parameters as the testbed has been designed to be used for all levels of users, basic, intermediate or advanced.

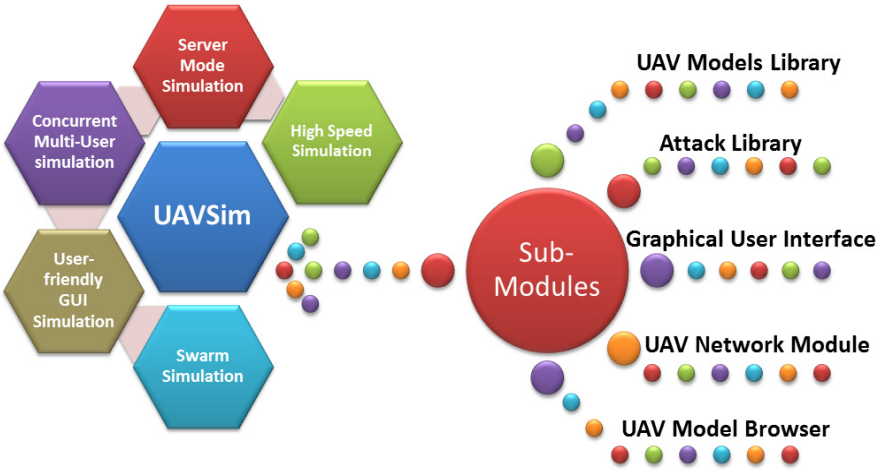

Fig. 1. UAVSim Design and Features. It shows the various modules [16] (*on the right*) which constitute UAVSim, as well as various simulation options.

2.2 Server Mode Simulation

In order to enhance the performance, a high performance computer can also be utilized in our simulation testbed. The connection details to a server or high performance computer can be set using the GUI by the administrator or the person setting up the testbed for the initial use. It should be noted that the core testbed simulation files should be installed on the server prior to this setup and *ssh* should be enabled on the high performance computer to enable seamless communication and execution.

2.3 High Speed (No-GUI) Simulation

While the testbed has a well-designed GUI, the aim of providing a non-GUI option was to enhance the performance. There is an option of express command mode execution as well, which prints the minimum required simulation statistics in order to let the user know that the simulation is running and the computer is not frozen. Using this option, the simulation can be run at the maximum speed and thus gives the best

performance. This mode was primarily designed for Server mode simulation because the communication with the server might slow down execution. Nevertheless, this mode can be used on the desktop mode as well as the server mode.

2.4 Concurrent Multi-User Simulation

The testbed also provides a multi-user option which allows multiple users to concurrently run their simulations through their individual machines. This option utilizes the Server Mode of the testbed. As mentioned before, if the testbed needs to be used for the high speed simulation or, by several users at the same time, a non-GUI server option is available. One of the most important prerequisites to use this option is the connection oriented access availability on the server to all the user accounts. This is necessary in order to enable the independent simulation for each user. The core simulation modules need to be installed on the server while users remotely connect to the server using UAVSim. The UAVSim, once configured with the server and connection details, automatically connects to the server and displays results in a console window. It should be noted that the multi-user simulation is only available in non-GUI option.

2.5 Swarm Simulation

Although the simulation testbed was primarily developed for UAVNet security simulation, it also supports the UAV swarm simulation. This feature lets users test the network behavior when large numbers of UAVs are used for any specific application. The use can be commercial, civil or military in nature but in case of swarms, usually it should be a sensor based application with a large number of sensors. The performance for swarm simulation using a large number of nodes has also been evaluated.

3 Performance Results and Analysis

In order to demonstrate the usefulness of the simulation testbed, it is necessary to evaluate its performance using the already available computing infrastructure. Usually, in an academic or research setup, it is difficult to purchase new equipment as soon as it is needed. Therefore, enabling the use of a testbed to allow users to simulate the behavior of such a complicated network in the most cost-effective manner is of utmost importance. It should be noted that all simulations were 300 seconds in length. Other parameters are being varied in different performance tests.

3.1 Number of Wireless Nodes

We first evaluated the system performance with variable number of wireless nodes in the simulation scenario. Two cases were evaluated. Case I being variation of number of attack nodes while Case II involves use of just regular UAV nodes in order to show that UAVSim can be used for simulating UAV swarms as well as UAVNet security.

It is clear from Fig. 2 and 3 that the performance varies linearly (1:1) with the increasing number of malicious nodes. Since malicious nodes are responsible for most of the traffic in the network, the time varies linearly with respect to their number.

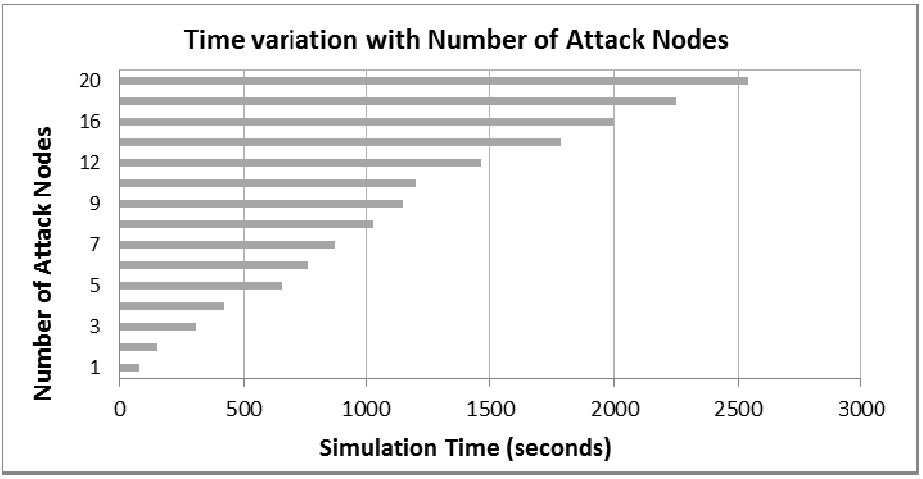

Fig. 2. Simulation time variation with varying number of Attack Nodes

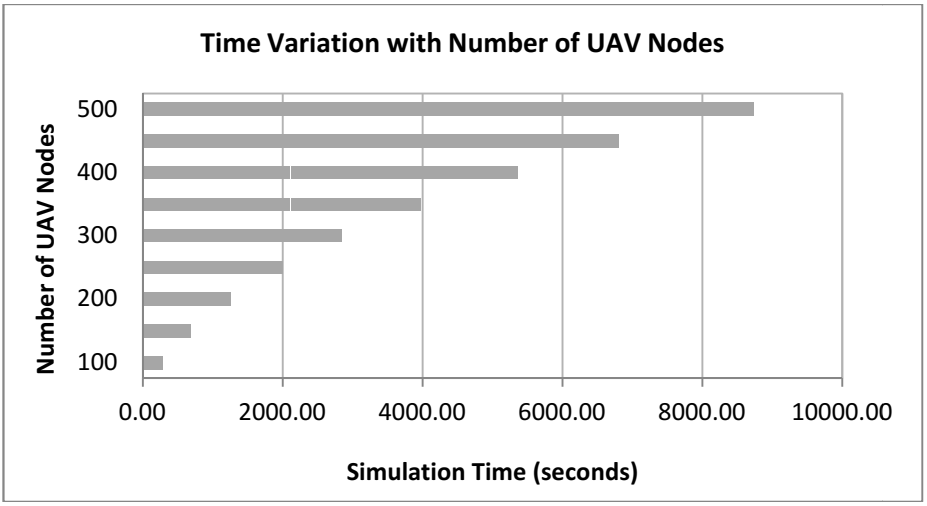

Fig. 3. Simulation time variation with varying number of regular UAV Nodes

Further, if we wish to perform simple UAV simulations using a large number of UAV nodes in absence of malicious nodes, the performance is again linearly dependent on the number of UAV nodes but the variation is about 1:100. This means that the addition of one malicious node would increase the simulation time about the same as adding 100 UAV nodes.

3.2 User Interface

The second performance metric was the user interface. It is clear that having a GUI displaying the network animation and various network statistics during a CPU intensive operation might impact the performance up to some level. Therefore, we varied the simulation parameter similar to the last performance test and tried to measure the simulation speed. As clearly shown in Fig. 4, GUI does impact the simulation up to some extent but the variations keep increasing as the number of nodes was increased.

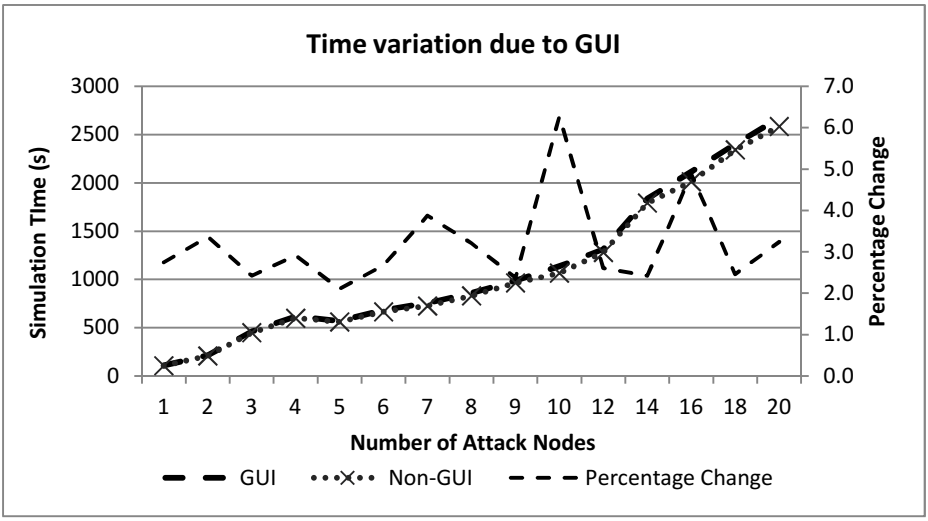

Fig. 4. Effect of GUI (graphical user interface) usage on the total simulation time

3.3 Number of Concurrent Users

The third performance test was done using a number of concurrent users in the server mode option. All the users were using the desktop version of the UAVSim while they were already configured with server details. As mentioned earlier, the server based simulation works only in the non-GUI mode to enhance the execution performance and reduce the server to PC communication. The number of users was varied from 1 to 6 and the execution time was evaluated for two types of simulation scenarios. Fig. 5 shows the performance test results for Scenario I, which included malicious nodes. The number of malicious nodes was varied in this case keeping number of regular UAVs as 10 because these nodes generate more traffic in the network and are responsible for increasing the execution time. On the contrary, Scenario II does not use malicious nodes and uses only regular UAV nodes and the results are shown in Fig. 6. Please note that the two separate vertical axes show the variation of simulation time for two different numbers of nodes in each case. The error bars show the maximum and minimum time while the points depict the average time.

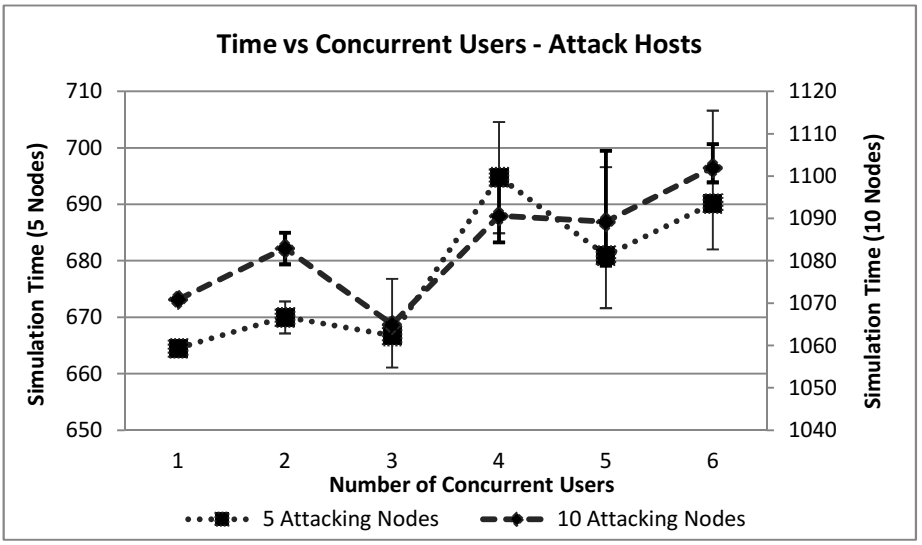

Fig. 5. Impact of number of concurrent users for 5 and 10 attack nodes

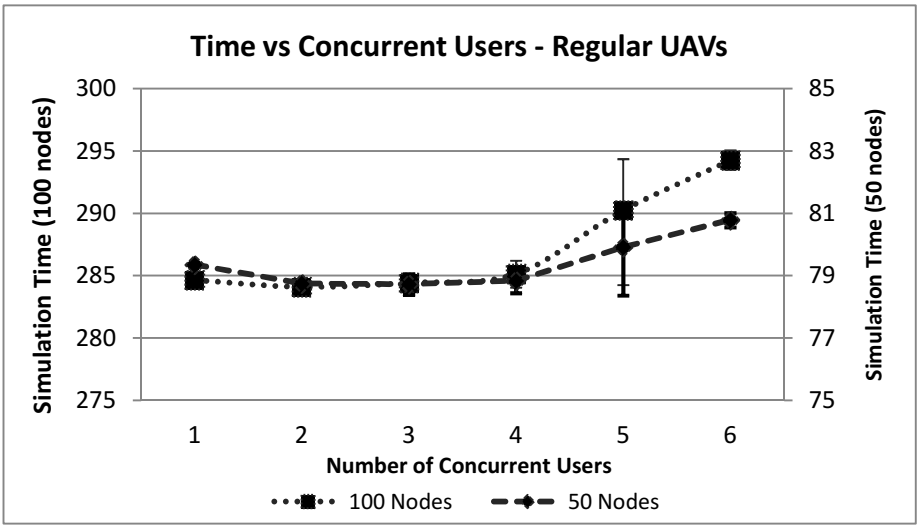

Fig. 6. Impact of number of concurrent users for 50 and 100 regular UAV hosts

3.4 Analysis

Various performance tests performed on UAVSim give us valuable insights in terms of the usability of the testbed. Although some simulation times are quite high in case of swarm simulations of a large number of nodes, for the primary purpose of security

simulations, the performance is reasonable. Some important points which can be noted from the analysis are as follows –

- Simulation time varies almost linearly with the number of nodes in case of security simulations while in case of swarm simulations, the simulation time varies exponentially.
- Performing a simulation using the GUI has little impact on the performance. It can be easily inferred that the simulation being processor-intensive, is not affected by the use of graphics.
- Performance analysis for multiple users using the testbed in server mode reveals that the performance does get affected with increasing number of users but the overall percentage variation is less than 5% in all cases.
- Surprisingly, in some cases, the average simulation time is reduced when the number of concurrent users increases. But the variation in minimum and maximum shows that total system performance is not affected that much.
- The attack simulation for 20 attack nodes took less than an hour. Practically, this number would be much less, for example, we need 4 attack nodes for a GPS spoofing attack [18] and thus, the simulation capability is quite extensive.
- The increase in time due to the increase in the number of concurrent users can be easily predicted using the obtained simulation results. Since the variation is not exponential, the simulation testbed seems quite capable of handling more than 20 users concurrently on a regular server.

4 Conclusion

Simulation time analysis for the previously proposed testbed UAVSim are presented in this paper to demonstrate its use in generic computing environment instead of high performance parallel machines. Performance enhancement using advanced machines can't be ignored. However, due to the unavailability of expensive hardware, a lot of researchers are forced to be limited. Therefore, the usability of the testbed for such usage has been proved through various performance tests. The simulation time for a 300-second simulation for various cases show that the performance of the software simulation testbed is quite reasonable and lets user adjust various options as per their requirements. Interactive GUI, additional result analysis module, model browsing capability from other model development software, enhanced high speed mode of operation, support of concurrent users, etc. are some of the features which make this software simulation testbed an ideal simulation environment for UAV simulations in generic computing environment. Work is still in progress for enhancing the performance and adding various other features to make it more user-friendly.

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