An Experiment Design Framework for the Simulator of Wireless Ad Hoc Networks

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1 Introduction

Computer simulation allows one to implement in software a model of an actual, physical system in order to gain insight into the process without interaction with the real, physical system. To perform a computer simulation one must follow a series of steps. Firstly, a mathematical model that approximates the behavior of the process must be designed. Next, a computational implementation of this model must be created. Finally, the computational model is executed and the results it produces are analyzed with statistical methods.

Computer simulation has been an invaluable tool in many fields of research, including chemistry, physics, and, of course, computer science. Since simulations do not require any equipment other than a modern computer, they may be used to generate insight into systems that would otherwise be too costly to experiment with in real life. Additionally, a process which normally occurs over a long time period can be simulated faster than it would occur real time.

My project is defined in the context of the simulation of wireless networks. There are two types of wireless networks in common use today. Infrastructure based networks have one or more stationary access points that act as gateways for all of the computers, or nodes, in the network. In order for two nodes to communicate, they must relay their traffic through the access point. Infrastructure networks are carefully constructed and managed by humans. Ad hoc networks, on the other hand, are not managed by humans and don't rely on any pre-existing infrastructure. By definition, an ad hoc network spontaneously forms when nodes come in proximity of one another; predetermined algorithms take charge of establishing a system of routing messages from source to destination. These algorithms patch the nodes together so any node is able to communicate with any other node.

More specifically, I will examine the simulation of Mobile Ad Hoc Networks, or MANETs. In a MANET, each computer acts independently and is therefore a member of an ad hoc network. The Simulator for Wireless Ad Hoc Networks (SWAN) is a project which aims to replicate a real MANET through computer simulation. The goal of SWAN is to produce a virtual environment to study the many parameters that can affect MANET performance. Using SWAN, models of physical processes can represent environmental effects, such as the dispersal of a chemical plume, or variations in temperature and barometric pressure. These environmental effects interact with models of wireless nodes that may be constructed to react to some characteristic. In turn, this characteristic can be measured, and the nodes are able to respond to variations of the characteristic by communicating with each other. SWAN records statistics pertaining to these interactions for later analysis.

MANET simulation studies require a great deal of organizational methodology. My thesis is that in order to make MANET simulations more credible, one can rely on a system that guides the experimental design, helps with the execution of multiple, simultaneous experiments, stores the results in a database, and creates mechanisms for their easy visualization. My contribution to the MANET community will be a web based application to achieve all these goals and a case study demonstrating its positive impact. Although this application will work directly with SWAN, I expect that the framework I am designing can be generalized to work with other MANET simulators.

2 Background

According to Merriam-Webster (2007), the scientific method consists of "principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses." It is important that this method is followed, and that the details of the experimental setup are shared so that readers of any particular MANET publication are able to replicate any experiment they come across. The most important characteristic of an experimental study is that the study is credible; however, this is not the case with MANET studies today.

Kurkowski et al. (2005) show that the vast majority of MANET simulation studies are unreliable. They believe that credibility in experimental research is contingent upon four factors. First, experiments must be repeatable. Second, experiments must produce results that are not specific to a single scenario. Third, the experiments must exercise the characteristic(s) of the system that we really want to study. Finally, statistical analysis of output must be held to high standards. I am particularly interested in two of these aspects:

1. A reader ought to be able to repeat experiments found in any particular journal article, presentation, conference proceeding, etc. Currently, experiments are not repeatable because a vast amount of experimental parameters remain unpublished for the sake of reducing the page count of a paper. If the results and conclusions documented in a publication cannot be replicated then the study lacks credibility.

2. According to Kurkowski et al. (2005), the analysis of the data resulting from MANET simulations is the downfall of many studies. Confidence in statistics is greatly improved as the number of samples increases. Performing an experiment only once, using too few samples, neglecting to compute confidence intervals, or using wrong methodology are common pitfalls that plague researchers.

Because researchers sometimes neglect one or more of the four aspects of credible experiments, few experiments described in current research have been successfully repeated. My thesis addresses the two issues highlighted above and proposes a solution to avoid them. Subsequently, the contribution of my work will make steps towards reestablishing credibility and reliability in MANET simulation studies. Section 3 discusses the specifics of how I will address these issues.

3 Project Description

A crisis of credibility has arisen due to the poor application of the scientific method and from the fact that experimental conditions are regularly omitted from publications. Rigorously following the scientific method is a difficult task; especially when dealing with a multitude of simulation experiments. Furthermore, both Perrone et al. (2003) and Kurkowski (2006) call for detailed descriptions of published experiments to be available online so that researchers may further study a MANET model they find in the literature. Unfortunately, the vast configuration files required to perform a simulation simply cannot be published in the small amount of space available to conference and journal articles. Finally, Kurkowski et al. (2005) writes that those running simulations often leave key parameters undefined, or carelessly use default parameter values embedded in the simulator without paying attention to whether the particular variable in question has been changed from a prior release of the software. Consequently, the results produced are not credible and the experiments are unrepeatable.

To address these problems, I propose a web based framework which will facilitate organization in MANET simulation. The use of this web based framework will enable me to present the end user with a simple *wizard-style* interface accessible from any web browser. The interface will consist of a series of carefully planned steps to guide the experimenter in creating reliable MANET simulation studies in the style of the scientific method. This guidance helps researchers automate tasks that would otherwise be confusing, error-prone, or difficult to those who are unfamiliar with MANET simulation.

The initial step in a SWAN simulation is experiment generation, thus, a user of the interface will be guided through this process. All of the configuration parameters used by SWAN will be stored in the database so they are easily accessible for later use. The framework will then execute SWAN using the generated experiment. Finally, the results of the experiment will also be archived in the database. In doing so, both the configuration parameters and the results of experiments will be at hand for quick reference at the time a publication is prepared.

When an experiment is complete, the framework will mine the database of results and apply rigorous output analysis methodology to the data. A common pitfall of simulation studies is either accepting the first set of results as a generalized result for all scenarios of a simulation, or not using proper statistical analysis techniques with varying forms of output.

My framework will automate statistical analysis, thereby eliminating the introduction of human error. An article by Sanchez (2005) on experimental design has brought to light efficient ways in which to implement and analyze simulations. I will implement some of these techniques as discussed in Section 4.

4 Methodology

My project will be implemented using a modern framework for the creation of web applications called *Ruby on Rails*. (Ruby is a programming language which I have already studied independently, and Rails is a framework for developing database backed web applications.) I have already read multiple books about Ruby and Rails, such as Ruby for Rails by Black (2006), and The Pragmatic Programmers' Guide to Ruby by Thomas (2005). Additionally, I have experimented with Rails by writing a few small web applications.

The guidance that the framework will provide to users is a key component in ensuring that the scientific method is followed. For instance, quantifying the effect of a single variable in the simulation is often a topic of interest to a researcher. This is addressed by *sensitivity analysis*, a process in which one keeps all variables constant while running experiments for different values of single variable. The researcher can then draw conclusions about the effect of that variable by analyzing the data produced for each value experimented.

Of course, this means that the researcher must run one experiment for every value of the variable to be studied. This may seem trivial for a small number of variables; however, as the number of values for the many variables increases, a proportional number of experiments must be run. The number of experimental runs needed for all combinations explodes rapidly. For example, suppose that we have k variables, x_k, each with n levels. Therefore, in order to run enough experiments to cover every possible combination of these variables, we must compute the Cartesian product of the sets of all possible values for each variable (see Equation 1) which results in n^k different experiments.

$$x_1 \times x_2 \times ... \times x_k \quad (1)$$

There exists a technique called 2^k factorial design that will greatly reduce the number of points in experiment space that need to be run to extract meaningful results. According to Sanchez (2005) and Law and Kelton (2000), the processing time for simulation runs will in turn be greatly reduced. 2^k factorial design will enable users to utilize the framework to provide detailed, error free statistics for any simulation in the database.

5 Significance and Conclusion

My work fits well with Professor Perrone's own research agenda. In Perrone et al. (2003), Perrone recognizes the need for carefully constructed experiments and the full disclosure of the conditions in which the experiments were carried out. My thesis addresses these issues and closely ties into and advances Professor Perrone's own research.

I expect that my work could have a positive impact in the MANET community by outlining a reasonable solution that addresses some of the problems that undermine the credibility of MANET simulation studies. I expect that my solution will be easy to adapt to work with other simulators; however, SWAN will be the focus of my research. I will offer mechanisms for simplifying experiment design, execution, and analysis.

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