A Case Study of Networks Simulation Tools for Wireless Networks

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Abstract

Networking community is largely depend on simulation to evaluate the behavior and performance of protocols for wireless networks, simulations are a good compromise between cost and complexity, on the one hand, and accuracy of the results, on the other hand. Since there are many simulators for wireless networks, it is often difficult to decide which simulator to choose. To help shed light on this issue, we discuss six "Widely Used" network simulation tools along with their associated strengths and weakness. To determine the state of wireless networks simulation studies, we surveyed the several primer conferences papers from years 2000-2008. From our survey, we found some important pitfalls and issues. We then summarize simulation study pitfalls found in our survey. Finally, we present our research results with the hope to aid developers in the selection of an appropriate simulation tool and to show them how to avoid common pitfalls to improve the reliability and repeatability of simulation based studies.

1. Introduction

The modern information society will continue to emerge, and demand for wireless communication services will grow. Future generation wireless networks are considered necessary for the support of emerging services with their increasing requirements. Future generation wireless networks are characterized by a distributed, dynamic, self-organizing architecture. The emergence of these wireless networks created many open issues in network design too. More and more researchers are putting their efforts in designing the future generation wireless networks. There are three main traditional techniques for analyzing the performance of wired and wireless networks; analytical methods, computer simulation, and physical measurement or a testbed measurement. Traditionally, formal modeling of systems has been via a mathematical model, which attempts to find analytical solutions to problems and thereby enable the prediction of the behavior of the system from a set of parameters and initial conditions. However, it is widely known that comprehensive models for wireless ad hoc networks are mathematically intractable. On its own, each individual layer of the protocol stack may be complex enough to discourage attempts at mathematical analysis. Interactions between layers in the protocol stack magnify this complexity. The construction of real testbeds for any predefined scenario is usually an expensive or even impossible task, if factors like mobility, testing area, etc. come into account. Additionally, most measurements are not repeatable and require a high effort. Simulation is, therefore, the most common approach to developing and testing new protocol for a wireless network [1]. A proper method is needed to analyze the collected data. Even though simulation is a powerful tool, it is still occupied with potential pitfalls [2, 3].

2. Related works

There are several surveys, comparisons, and also some case studies about wireless network simulators. They all differ with respect to the selection of evaluated simulators, the intention of the work, the focus of the potential comparison and the level of detail. Table 1 (see appendix) summarizes the previous related works.

All of the works listed in table 1 (see appendix) consider different simulators or differ in their aim from this paper/report. The works parented in [5, 7, 8, 9, 10, 12] are the close to our work as they include some common simulators J-Sim, OMNeT++, and ns-2, which we also consider for our study. However, [5] examines their suitability for simulating the failure of critical infrastructures like electricity or telecommunication networks. This is very unrelated to what we present here. A huge list of simulators is presented in [7, 9] however, they do not give a comparative study. Rather, their works consists of more or less description of each simulator tools independently. In [8] authors give an overview about

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the different issues in wireless networks on a general basis. Only at the end of their work they presented a table comparing the considered simulation tools according to different features such as their language, the available modules, and GUI support, etc. the most detailed comparison is presented in [10]. However, they consider all the simulators from an industrial research point of view, which are less relevant for academic researchers. They also miss several practical issues regarding the credibility and reliability of the tools. In [12] authors presented a survey study of more then 2200 research papers in the field of network simulation studies and point out several systematic flaws in that. We follow the similar kind of work line of [12] but with different aims. Our goal in this paper is to make a basic contribution to the wireless network community by a) comparing simulation tools on the basis of several features and a survey report of more then 450 research papers in the field of system and networks in recent years (2000~2008), b) listing our recommendations for the designers of protocols, models, and simulators.

3. Networks simulation tools

For network protocol designers, it is often difficult to decide which simulator to choose for a particular task. Therefore, we conduct a survey to find a wireless network simulator that provides a good balance between availability of ready to use models, scripting and language support, extendibility, graphical support, easiness of use, etc. The survey is based on a collection of a number of criteria including published results, interesting characteristics and features. From our survey results, we broadly categories network simulators as: “Widely Used” simulators and “Other” simulators. We discuss more about these two categories in the later sections of this paper. The network simulators taken into consideration as “Widely Used”are Ns-2, GloMoSim, J-Sim, OMNet++, OPNet, and QualNet.

3.1 Comparison

In this sub section we summarize the most interesting capabilities, advantages, and drawbacks of existing tools for wireless networks in table 2 (see appendix). Table 2 (see appendix) has all six simulators considered in the previous section listed in the consecutive columns and special features/capabilities in the context of all six simulators in the consecutive rows, respectively.

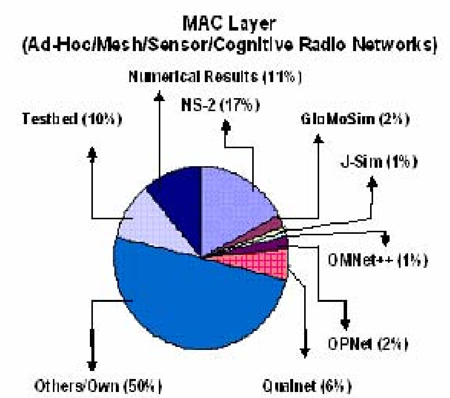
Wireless Networks simulators exhibit different features and models. Each has advantages and disadvantages, and each is appropriate in different situations. In choosing a simulator from the available tools, the choice of a simulator should be driven by the requirements. Developers must consider the pros and cons of different programming languages, the means in which simulation is driven (event vs. time based), component-based or objectoriented architecture, the level of complexity of the simulator, features to include and not include, use of parallel execution, ability to interact with real nodes, and other design choices. While design language choices are outside of the scope of this paper, there are some guidelines that appear upon looking at a number of already existing simulators. Most simulators use a discrete event engine for efficiency. Component-based architectures scale significantly better than object-oriented architectures, but may be more difficult to implement in a modularized way.

3.2 Analysis

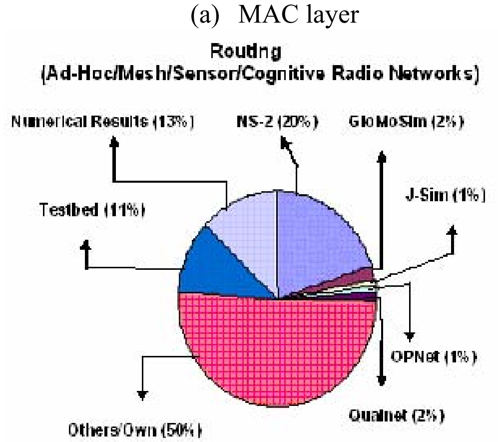
In the previous section we provide the background on a number of different network simulators and present the comparison of some important features of each. In continuation of our research work, we present our survey results to take up on the credibility issues of simulation studies in wireless networks, and to alert the researchers on some common simulation issues and pitfalls. We conducted a survey on wireless networks, especially on Ad-hoc/Mesh/Sensor/Cognitive Radio networks studies published in some of the premiere conferences of the wireless networks from years 2000 to 2008. Table 3 (see appendix) lists the name of all conferences that we considered in our survey. We only included the full papers on MAC and Routing layers in our survey, not the poster and demonstration papers. We reviewed each paper individually avoiding word searches or other means of automatically gathering results. For consistency, the same person reviewed all of the papers; to validate the results and to correct the few inconsistencies we had a second person review all of the papers again.

Table 3 (see appendix) shows the detailed database of survey data; here, we categorized our data into mainly two categories: MAC layer and Routing layer. Our database includes all related fields papers from above listed conferences. From our survey, we come across many simulator tools, and we broadly classified them into two main categories: “Widely Used” network simulators and “Other” network simulators.

Figure 1 shows the simulator usage results of our survey at different levels of protocol stack, especially at Routing and MAC layers. From figure 1, it is also interesting to know that testbed or experimental studies are also gaining popularity in recent years, and their usage ratio is almost same in Routing and MAC layers. It also shows a good start from the wireless networks community to present more realistic, practical, and sound research results. But still there are many issues such as scalability, cost, area, etc., need to be addressed to make testbed or experimental setup widely accepted among the community. As of current research practice, simulation is currently the most feasible approach to the quantitative analysis of wireless networks. As we can see from figure1 NS-2 is the most popular/used simulator among the "Widely Used" network simulator tools. To our surprise we find numerical/mathematical results are more dominating than "Widely Used" tools (NS2 is an exceptional case), as general trend is to present rigorous simulation results than mathematically sound results in wireless networks community. It is worth to note that these numerical results also include the theoretical aspect of the field. From figure 1 we can find a very interesting observation that in both the layers other/own category is at the top. To know the reason we further expand survey results on other/ own category as shown in figure 2.



(a) MAC layer



(b) Routing layer

Figure 1.Simulator Usage in MAC and Routing layers

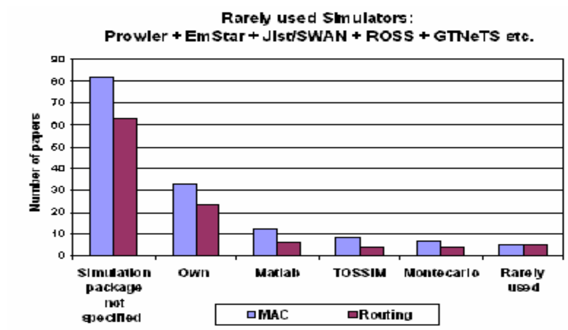


Figure 2. Survey results on "other/own" category

As we can see from figure 2 major part of other/own category is occupied by the simulator tools which are not specified in the papers. When the simulator used is not specified within a published paper, the repeatability and credibility of the simulation study are questionable. Second topmost category is "own" where researchers have used their self-developed or custom made simulation tools. It is also difficult, if not possible, to repeat a simulation study when the simulation is self developed and code is not available. Rest of the simulator tools, especially Matlab, TOSSIM, Montecarlo, and "rarely used" simulator tools, have a small portion of participation in wireless networks research. One very important fact come out in our survey is that a very few papers (hardly 3/4 papers) cited about the code availability, for whatever reasons but this issue really need an attention from the community. Further more, we obtained some interesting observations from our survey as shown in figure 3.

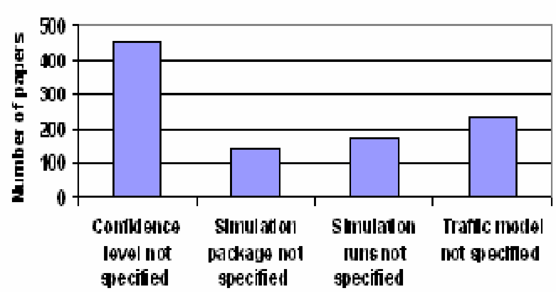


Figure 3. Simulation issues

The execution and analysis of any experiment/simulation study must be based on mathematical principles and need to be statistically sound. For any experimental/ simulation study to be statistically sound must present the number of times simulation runs, confidence levels that exist in the results, and a list of any statistical assumption made. To our surprise, the large numbers of papers don't even bother to present this basic information regarding their research results. As we see from figure 3 nearly 150 papers aren't independently repeatable because of the lack of simulation's information. Additionally, the papers often omitted simulation input parameters such as traffic model or type. As shown in figure 3 nearly 250 papers didn't specify any traffic model or type they have used. So, this lack of basic information raises many questions on the reliability and repeatability of wireless networks research. To raise the awareness on the lack of reliability, repeatability, and credibility of simulation based studies we have developed a list of common issues and pitfalls as the starting point for improvement. We have written the list from our own experiences with simulations as well as the experience of others in the field. Some common issues and pitfalls are identified from our survey. We summarize these issues and pitfalls into the following categories: simulation setup and initial assumptions, simulation execution, and output analysis. They are summarized with our recommendations in table 4 (see appendix).

This paper summarizes the current state of practice, and identified some of the difficult issues that must be resolved to increase the reliability and credibility of simulation based studies. Further more, wireless community should take some concrete steps such as standardization of simulation tools and creating some universal virtual testbeds to resolve the points of consensus as mentioned above. Universal virtual tesbed could be a very useful for all the research groups around the globe and can also be used as standard measuring tool for wireless networks community.

4. Conclusions and future works

In this paper, we discussed strengths and weaknesses of six most "widely used" network simulator tools based on a couple of papers and our survey. Then, with the results of our survey we show that the majority of results of simulation studies of wireless networks published in technical literature have many pitfalls/issues. With this paper we documented these pitfalls and some important issues with some recommendations to increase the reliability and repeatedly of simulation studies. We are currently extending in breadth and in depth the investigation reported in this paper. First, we are attempting to include a survey on system simulator tools and consolidating with our present work to come up with a guide line on cross layer designing. Second, we want to present a comparative study on different protocols in different simulator environments to further solidify our survey results.

Finally, we hope, the results presented in this paper will motivate the researches to put their efforts in thorough descriptions of the simulation scenarios and taking care of pitfalls in simulation studies of wireless networks.

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Appendix

Reference	Type of Study	Simulator Tools	Scope of Study
[4]	Comparison	Opnet, ns-2	Initialization, accuracy
[5]	Comparison	Opnet,ns-2, QualNet, OMNeT++, JSim, SSFNet	For critical infrastructure
[6]	Comparison	ns-2, TOSSIM	Models, visualization, architecture, components
[7]	Description	GloMoSim, ns-2, DIANEmu, GTNetS, J-Sim, Jane, NAB, PDNS, OMNeT++, Opnet, QualNet, SWANS	Overview
[8]	Comparison	SSF, SWANS, J-Sim, NCTUns, ns-2, OMNeT++, Ptolemy, ATEMU, Em-Star, SNAP, TOSSIM	Models, type of visualization
[9]	Description	ns-2, GloMoSim, Opnet, SensorSim, J-Sim, Sense, OMNeT++, Sidh, Sens, TOSSIM, ATEMU, Avrora, EmStar	Overview
[10]	Comparison	Opnet, ns-2, OMNeT++, SSFNet, QualNet, J-Sim, Totem	availability/credibility of models, usability
[11]	Case Study	Opnet, ns-2, testbed	Accuracy of results
[12]	Survey	In general simulation study	Credibility , accuracy

Table 1. Related works on simulatior comapariosn

Sr. No.	Tools / Features	NS2	GloMo-Sim	J-Sim	OMNet++	OPNet	QualNet
1	Interface	C++/OTcl	Parsec (C-Based)	Java/Jacl	C++/NED	C or C++	Parsec (C-Based)
2	Available Modules	T/W/Ad/ WSNA	T/W/Ad	T/W/Ad/ WSNA	T/W/Ad	T/W/Ad/ WSN	T/W/Ad/ WSNA
3	Mobility	Support	Support	Support	No	Support	Support
4	Graphical Support	No or very limited visual aid	Limited Visual aid	Good visualization and debug facility	Good visualization and excellent facility for debug	Excellent graphical support, Excellent facility for debug.	Good graphical support, Excellent for debug.
5	Parallelism	No	SMP /Beowulf	RMI-based	MPI/PVM	Yes	SMP /Beowulf
6	License	Open Source	Open Source	Open Source	Free for academic and educational use	Free academic License for limited use	Commercial
7	Scalability*	Small	Large	Small	Large	Medium	Very Large
8	Documentation and user support	Excellent	Poor	Poor	Good	Excellent	Good
9	Extendibility*	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
10	Emulation	Limited	Not Direct	Yes	Limited	Not Direct	Yes

T: Traditional Models (eg. TCP/IP, Ethernet)
W: Wireless Support (eg. Propagation model, IEEE 802.11)
Ad: Ad-Hoc Support (eg. AODV, DSR)
WSN: Wireless Sensor Networks Support (eg. S-MAC, Direct Diffusion)
WSNA: Advance Wireless Sensor Networks Support (eg. Zigbee, Energy Model)
*Concerning table 2, as no exact metrics are available for scalability and extendibility, we define Very Large > Large> Medium > Small, and Excellent > Good > Poor, respectively.

Table 2. Comparison of different network simulation tools

Sr. No.	Conference Name	Years	Ad-Hoc/ Mesh Networks		Sensor Networks		Cognitive Radio Networks		Total	Specialized area
			Routing	MAC	Routing	MAC	Routing	MAC		
1	ACM MobiCom	2000~2008	25	19	10	5	-	-	59	Ad-hoc/ Mesh/sensor Net. Tracks
2	ACM/IEEE MobiHoc	2000~2008	38	32	11	13	-	-	94	
3	ACM Sigcomm	2000~2008	27	3	4	17	-	-	51	
4	IEEE Infocom	2000~2008	45	26	9	6	-	-	86	
5	ACM SenSys	2003~2008	-	-	24	-	-	-	24	
6	EWSN	2004~2008	3	-	12	24	-	-	39	
7	IEEE Percom	2003~2008	5	10	5	10	-	-	30	
8	IEEE CrownCom	2006~2008	-	-	-	-	4	41	45	Cognitive Radio
9	IEEE DySpan	2005~2008	-	-	-	-	1	34	35	
10	IEEE CogART	2008	-	-	-	-	1	4	5	
11	IEEE MilCom	2005~2008	-	-	-	-	-	17	17	
		Total	143	90	75	75	6	96	485	

Table 3. Survey data

Category	Issues/Pitfalls	Recommendations
Simulation setup and initial assumptions	Network area, number of nodes, mobility Models, node distribution, traffic model, transmission range, bidirectional communication, capturing effect, simulation type: terminating vs. steady state, protocol stack model, RF propagation model, and proper variable definitions.	• Most of these issues can be easily solved by proper documentation. • Due to space limitation, sometimes publications can include only major settings. In this case authors can provide the external links or references, which include all the needed information. • Try to tune setting some parameters against an actual implementation if possible or improve the abstraction level of used models.
Simulation execution	Protocol model validation, PRNG validation, scenario initialization: empty caches, queues, and table; and proper statistics collection.	• Validating protocol models against analytical models or protocol specifications • Determining the number of independent runs required. • Proper setting and address of random number generators • Collecting data only after deleting transient values or eliminating it by proper preloading routing cache, queues, and tables.
Output analysis	Single set of data, Statistical analysis: autocorrelation, averages, aggregation, mean , and variance; confidence level	• Experiment should be run for some minimum number of times • Analysis should be based on sound mathematical principles • Provide proper confident interval for a given experiment.

Table 4. Important issues and recommendation