Framework for Developing Realistic MANET Simulations

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Abstract

Mobile Ad hoc Networks have become an attractive option for military and disaster-response operations. Its ad hoc nature allows for fast deployment and requires no pre-existing network infrastructure.
Most of the MANET protocol development is achieved by means of simulation due to the cost of running real world applications. However, it has become apparent in recent research papers that the simulations of these networks do not adequately reflect reality.
In this paper, we aim to investigate some of the assumptions that are made during MANET protocol development and how these assumptions affect the results of these studies. A framework is suggested to help assist future studies to be more attentive to these assumptions. This framework aims at improving the credibility of MANET research for future deployment of MANET systems.

Keywords: *Realistic, Mobile Ad hoc Network, Framework, Credibility*

1. Introduction

A Mobile Ad hoc Network (MANET) is a collection of mobile network nodes with the capability of transmitting and/or receiving information wirelessly. Each node in the network can act as a sender, receiver or intermediate node during communication. There is no need for a network infrastructure to assign routing paths or maintain them; routes are dynamically discovered by path finding protocols (Wu et al., 2007).

Due to this ad hoc network architecture, it is ideal for disaster response and military operations where no pre-existing infrastructures exist. This allows for rapid deployment and for mobility within the network. Simulation tools are widely used in MANET protocol development (Kurkowski et al., 2005; Andel and Yasinac: 2006). In recent research papers, (Brakmo & Peterson, 1996; Cavin et al., 2002; Chin et al., 2002; Pawlikowski, 2003; Kurkowski et al., 2005; Andel & Yasinac, 2006) it has been noted that these simulated results do not match real life applications. The simulation tools themselves make assumptions about the network that most users of the application are unaware of. This leads to conflicting results and decreases the credibility of the research. A key example of this is when researchers only test their application on the ISO layer it will be deployed on, but does not consider the underlying layers that also play a major role in the performance of these protocols.

Layer	Attacks
Application layer	Data corruption, Repudiation
Transport layer	Session jacking, Side-along jacking, SYN flooding
Network layer	Wormhole, Blackhole, Byzantine, flooding, resource consumption, location disclosure attacks
Data link layer	Traffic analysis, monitoring, disruption, WEP weakness exploitation
Physical layer	Jamming, interception, eavesdropping
Multi-layer attack	Denial of Services, impersonation, replay, man-in-the-middle attacks

Table 1: Taxonomy of MANET attacks on ISO model

Table 1, illustrates a taxonomy of ad hoc network attacks as conceived by (Wu et al., 2007). This illustrates the potential influence other layers of the ISO can have on the MANET application. These attacks specifically influence the MANET, yet the MANET is susceptible to numerous other environmental and physical constraints that are not always modelled in the simulation or are they mentioned by the researchers as assumptions (Andel and Yasinac: 2006). This leads to unrealistic expectations for real life applications.

Andel and Yasinac (2006) identified the following problems with the current state of MANET research

- Research could not be independently replicated
- Statistical validity could not be ascertained
- Non-realistic radio models used to develop protocols
- Sparse validation of test models
- Traffic generation does not reflect real world application
- Lack of sensitivity analysis

In section 2 we provide the motivation for the need of a standardized framework for MANET, section 3 we will discuss the common pitfalls of MANET simulated studies, in section 4 we propose our own framework for conducting MANET simulations as well as discuss the phases of the framework, in section 5 we conclude.

2. Motivation

The premise of MANET protocol simulation is that if two protocols execute in identical situations with all variables set to the same value, the one which performs best in a head-to-head comparison would also perform best in real life applications (Kurkowski et al., 2005). Unfortunately this is not always the case (Kurkowski et al., 2005; Andel & Yasinac, 2006)

This paper aims to illustrate the need for a standardized MANET simulation framework for fair evaluation of MANET protocols. In recent publications the simulation of MANET protocol testing has been disputed (Brakmo & Peterson, 1996; Chin et al., 2002; Pawlikowski et al., 2002; Pawlikowski, 2003; Kurkowski et al., 2005; Andel & Yasinac, 2006). In this section we shall look at the common problems and pitfalls in MANET simulation.

2.1 Current state

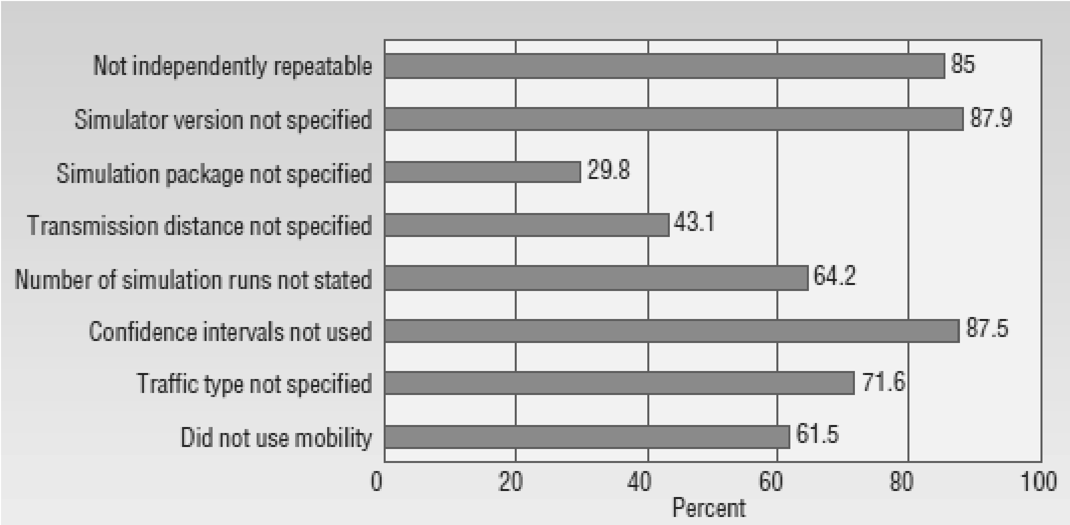

Figure 1 : Current state of MANET simulation (Kurkowski et al., 2005)

Andel & Yasinac (2006) performed a survey of MANET simulations published in the proceedings of the ACM International Symposium on Mobile Ad hoc Networking and Computing (MobiHoc) from 2000-2005. A common problem with MANET simulations, as cited by Andel & Yasinac (2006), 85% of the experiments could not be independently repeated or verified. Kurkowski et al. (2005) states that, if the simulation package used to simulate the results is not stated it directly compromises the repeatability of the study. According to the survey 29.8% of the papers did not even state the software package used to achieve their results.

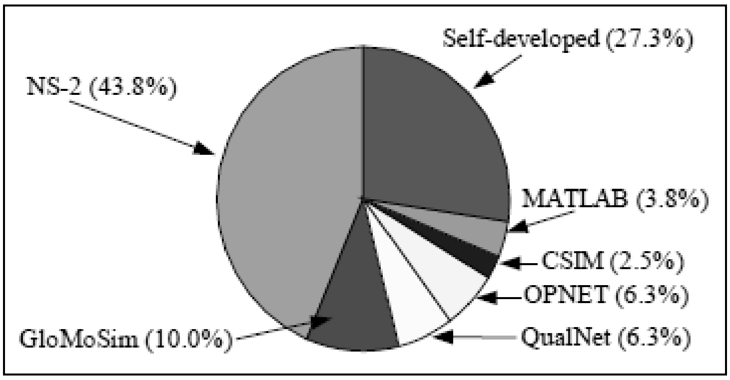

Figure 2: Simulation usage from MobiHoc survey (Kurkowski et al., 2005)

Figure 2 illustrates simulation tool usage statistics for MANET MobiHoc from 2000-2005. As one can see from the figure, a large portion of the simulation tools (27.3%) is self developed. Often these tools are not validated and as such their results can not be trusted with confidence. Even the standard applications such as OPNET and NS-2 have been reported to contain flaws and inconsistencies. Garrido et al. (2008) did a comparative study between NS-2 and OPNET and found several discrepancies, on how these two tools differ when handling different scenarios, Cavin et al. (2002) compared Global Mobile Information Systems Simulation Library (GloMoSim), OPNET and NS-2. They implemented a flooding protocol in each of these packages, theorizing that if these packages simulated reality accurately the results should be similar, yet upon inspection of results these tools each reported different results. They came to the conclusion that at most only one of these applications could simulate reality accurately but based on their results it seemed apparent that all of these tools might be wrong.

Another key concern is the documentation of test parameters and assumptions made. NS-2.31 has over 600 default variables set within it ns-default.tcl file which could have direct impact on the results of one's simulation results (Fall & Varadhan, 2003). Obviously it would be impossible to report the values of each result within this file but authors are able to provide a secondary source to configuration files like these to assist in validation of their work. Similarly it is impossible to perfectly model reality hence any assumptions or generalizations should be stated as to not mislead the reader.

3 Common pitfalls

3.1 Ill-conceived scenarios

A common practice in MANET simulation is to simulate the environment in 2-D with each node having a same sized, circular radius, in which its radio link can communicate, whilst each node moves according to a random distance vector at a constant speed. This scenario does not realistically represent real world applications for which these protocols are designed.

In military operations the most common applications of MANET technology is peace relieve or disaster response. The greatest obstacle for MANETs in these environments is obstacles and debris disrupting radio signals (Stepanov & Rothermel, 2008). This affects the signal range and connectivity of nodes within the network. Hence proper terrain layout and three dimensional spacing of objects play a large role in realistic scenario definitions. (Kurkowski et al., 2005; Andel & Yasinac, 2006; Stepanov & Rothermel, 2008) also noted that not all nodes have the same broadcast range or coverage, this specifically impacts protocols designed to improve node security or detect attacks on Wireless Sensor Networks, where key exchange and message propagation is of key concern.

Another key concern is the movement strategy implemented in the scenario. In most simulations movement is defined by a random movement vector which the node follows at a constant speed. In real scenarios, movement is clearly defined by emergency procedures or doctrine. Also, different nodes have different movement characteristics such as speed, acceleration and turning capabilities, all of which is directly influenced by the terrain.

3.2 Simulation tool capabilities

As was illustrated in Figure 2, there are several simulation tools, each with its own strengths and weaknesses. In order to simulate a MANET protocol one must be aware of the simulation tools shortcomings to properly delineate and be aware of the assumptions and limitations imposed by the tool.

Most of the shortcomings of MANET simulation mentioned thus far are as a result of simulation tool shortcomings; as such it is the responsibility of the researcher to confirm whether the tool does in fact perform in the way they claim it to. Validation of these tools forms a large part of this responsibility. Operation, like the NATO 2009 Exercise (NATO-OTAN, 2009), is a valuable source of information on real performances of MANET applications. Most simulation tools only use the network layer during simulation to determine protocol efficiency, yet Wu et al. (2007) illustrated that not only network layer needs to be simulated as the MANET is vulnerable to attack on several layers. Specifically the physical layer has a large impact on the results of realistic simulations as it directly influences connectivity.

3.3 Simulation bias and statistical relevance

Researchers do not follow strict statistical practices when conducting MANET research.

According to Cavin et al. (2002) only 35.8% of research papers presented at MobiHoc stated the number of iterations used to achieve their results and only 12.5% provided a confidence interval for their results. Further more a common concern is the use of Pseudo Random Number Generators to introduce uncertainty into the model. NS-2 has a default seed value, as 12345 (Fall & Varadhan, 2003). If not explicitly set, within the ns-default.tcl driver file, it would results in correlation among test runs and negates most statistical analysis techniques and their results (Pawlikowski, 2003).

Improper simulation practices also introduce error into results. Researcher must make a clear distinction between steady state results and terminal state results. Steady state results assume paths among nodes are already established and an initialization phase has been completed before results start recording, this is to counter initialization bias. Terminal state usually includes initialization data and uses a temporal or event driven event to determine when to start and stop data collection.

In the next section we shall propose our framework for more realistic MANET simulations as well as provide a brief description of each phase of the model.

4. More realistic MANET simulation framework

The issues motioned in the previous section are not new. In 1999, DARPA hosted a workshop to discuss these issues, yet these recommendations are clearly not being followed (Leiner et al., 1996; Pawlikowski et al., 2002; Andel & Yasinac, 2006). Kurkowski et al. (2005) identified three phases in MANET simulation and testing, our model builds on their concept by subdividing each phase into several tasks that need to be completed in each phase.

Phases	Tasks
Simulation Setup	Scenario Definition
	Investigate Real World Concerns
	Simulation Tool Selection
	Delineation
Simulation Execution	Simulate Scenario
	Validate Model
Output Analysis	Analysis of results
	Publish Results and Process

Table 2: Proposed Model

4.1 Simulation setup

4.1.1 Scenario definition

There is no silver bullet when it comes to MANET applications. Each application has its own strengths and weaknesses hence in order to properly test these applications one needs an accurate real world scenario to test the efficiency of these applications. (Johansson et al., 1999) defined three scenarios in their paper to illustrate this point.

Disaster response procedures and military doctrine are readily available sources of scenarios. These scenarios make it easier for scientists, to define movement strategies and also make them more aware of how nodes would react in real life. The benefits of these scenarios are that they help identify real world requirements and could assist in doctrine development as well as disaster response planning.

4.1.2 Investigate real world concerns

With the help of a well defined scenario one can start taking a look at the impact of the real world on the simulation.

A key concern in this task is to determine each node's radio model capability as well as how it is affected by the environment. Next, it is important to determine each node's movement strategy and how it would be affected by the current environment. Lastly it is important to identify obstacles within the environment that would hinder either of the previous two metrics.

This task will also be a source of appropriate values for variables within the simulation. Values such as node transmission range, node movement speed, transmission speed, collision threshold. It is also important to consider how these values are predicted to be influenced by adverse climactic and environmental conditions within the scenario.

4.1.3 Simulation tool selection

With a better understanding of the real world one can start identifying concerns and needs for the planned simulation. By investigating existing simulation tools one can match these needs with what is offered by pre-existing tools as well as determine how feasible it is to extend these tools.

Key concerns in this task would be to determine how realistically the simulation tool is capable of simulating the radio model used in the scenario. Next it is important to investigate to which extent the researcher is capable of defining movement strategies to the nodes. Lastly it is important to determine if obstacles within the environment affect the radio model and if so to which extent and how realistically.

4.1.4 Delineation

Obviously it is nearly impossible to achieve a perfect match between what capabilities the tool offers and what is needed for a completely realistic experiment. This is to be expected as a simulation is just an abstract representation of reality. Hence it is important to take note of these discrepancies between reality and the simulated model. Explicit delineation protects the researcher from criticism, by clearly defining what is covered in the research and what is not (Hofstee, Erik, 2006). By providing clear delineation one also makes it easier for future researchers to attempt and improve on your research by addressing specifically what was not covered in your work, hence reducing the duplication of research.

Even though it is of vital importance to delineate in order to clearly define ones work, one should be wary of losing relevance. If one's model simplifies reality to too great an extent one starts to lose relevance and the research starts to lose value. Hence delineate as much as possible but only up until the point where the research still has significant value and contribute to the existing knowledge in the field (Hofstee, Erik, 2006).

4.2 Simulation execution

4.2.1 Simulate scenario

This task involves simulating the environment exactly as specified by the scenario while at the same time keeping in mind what is not covered in this experiment due to delineation.

A key concern in this task is to determine the state of the simulation. There must be a clear understanding of a terminal state experiment and a steady state as the results of each should be evaluated differently. If a Pseudo Random Number Generator (PRNG) is used the researcher should insure the number is statistically random enough for their needs, for example NS-2 uses a default seed of 12345 and if not set will skew results.

Another concern is the initialization bias; depending state in which one wishes to perform the simulation one must take initialization bias into account. Steady state simulations usually run for a set amount of time to counter initialization bias, yet terminal state experiments might be interested in the initialization as part of their data set.

Lastly the metrics recorded within the experiment is of concern, without the needed data capture the experiment is of little use (Pawlikowski et al., 2002). The investigation into the real world concerns could help identify these metrics.

4.2.2 Validate model

This is probably the area where most MANET simulations suffer the most criticism, simulation tools and models are not validated by governed organisations. Testing and experimenting of real life MANETs is an expensive and time consuming task hence the appeal of simulation as test medium. 75.5% of papers published in MobiHoc used simulation as means of testing (Andel & Yasinac, 2006). Yet only 7% of these papers claim to have partially validated their models.

Clearly on would not wish to validate each model by running a real world experiment, as this will negate the need for simulation. Other means exist such as mathematical calculations or consultations with industry experts to help validate models.

In this task one should not only validate the technical aspects such as radio models but also the scenario itself. Return to the source of the scenario and validate that the simulation does in fact accurately model the scenario plan. This could aid future planning and doctrine development.

4.3 Output analysis

4.3.1 Analysis of results

A key concern in this task is the confidence one has in the one's results. Proper statistical formulas should be used when conducting analysis.

Single sets of data are not sufficient to make well informed judgements. 64.2% of the simulations published in MobiHoc did not report the number of simulation executions that was used to achieve their results. A confidence is a tool to determine the range in which the population mean would locate relative to point estimates (Brakmo & Peterson, 1996; Sanchez, 2001). Dyer & Boppana (2001) illustrates a method of determining the number of iterations required to achieve a given confidence level.

4.3.2 Publish results and process

This task will determine if fellow researchers have confidence in your findings, as this will be the only source they have to validate your claims. Lack of documentation is a widespread problem in MANET simulations. 85 percent of MobiHoc research papers could not be independently duplicated due to lack of documentation (Kurkowski et al., 2005).

The problem is that a publication can only contain a limited amount of information; hence it is impossible to publish all 600 variable setting that NS-2. Data specific to the scenario or real world observations often get omitted due to space constraints but they are crucial to repeatability of experiments.

Secondary resources could be used to store these configurations. A recent trend in publishing test data on websites or Blogs as a means of collaboration is a very plausible means of sharing this data and helping to assist researcher collaborate with global partners.

The only concern is military and disaster plan information which should be handled with an air of secrecy and security. This does not prevent the researcher from providing fellow readers with information about assumptions and observations made during the experiment.

5 Conclusions

Clearly the inconsistencies and ominous simulation practices within the MANET community is not new observation (Leiner et al., 1996). Even after various papers have reported poor simulation practices within the community, these warnings seeing have gone unheeded (Cavin et al., 2002; Kurkowski et al., 2005; Andel & Yasinac, 2006; Stepanov & Rothermel, 2008). This has lead to loss of credibility within the research community (Pawlikowski et al., 2002; Pawlikowski, 2003).

The framework presented within this paper hopes to serve as a point of reference for future MANET research to re-establish credibility in MANET simulation results. Simulations based MANET research is a complex process riddled with pitfalls and opportunities to compromise the credibility of the study (Kurkowski et al., 2005). This paper illustrated some of these pitfalls as well as provided a guideline to assist in avoiding them. Hopefully by following this framework the credibility of the MANET simulations will improve.

References

Andel, T.R. & Yasinac, A., 2006. On the Credibility of Manet Simulations. *Computer*, 39(7), pp.48-54.
Brakmo, L.S. & Peterson, L.L., 1996. Experiences with network simulation. In *SIGMETRICS '96: Proceedings of the 1996 ACM SIGMETRICS international conference on Measurement and modelling of computer systems*. New York, NY, USA, 1996. ACM.

Cavin, D., Sasson, Y. & Schiper, A., 2002. On the accuracy of MANET simulators. In *POMC '02: Proceedings of the second ACM international workshop on Principles of mobile computing*. Toulouse, France, 2002. ACM.
Chin, K.-W., Judge, J., Williams, A. & Kermode, R., 2002. Implementation experience with MANET routing protocols. *SIGCOMM Comput. Commun. Rev.*, 32(5), pp.49-59.
Dyer, T.D. & Boppana, R.V., 2001. A comparison of TCP performance over three routing protocols for mobile ad hoc networks. In *MobiHoc '01: Proceedings of the 2nd ACM international symposium on Mobile ad hoc networking & computing*. Long Beach, CA, USA, 2001. ACM.
Fall, K. & Varadhan, K., 2003. *NS-Manual*. [PDF] Available at: http://www.isi.edu/nsnam/ns/doc/ns_doc.pdf .
Garrido, P.P., Malumbres, M.P. & Calafate, C.T., 2008. ns-2 vs. OPNET: a comparative study of the IEEE 802.11e technology on MANET environments. In *Simutools '08: Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems \& workshops*. Marseille, France, 2008. Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering.
Hofstee, E., 2006. Constructing a good dissertation: A practical guide to finishing a masters, MBA or PhD on schedule. Johannesburg, South Africa: Exactica. pp.20-29.
Johansson, P. et al., 1999. Scenario-based performance analysis of routing protocols for mobile ad-hoc networks. In *MobiCom '99: Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking*. Seattle, Washington, United States, 1999. ACM.
Kurkowski, S., Camp, T. & Colagrosso, M., 2005. MANET simulation studies: the incredibles. *SIGMOBILE Mob. Comput. Commun. Rev.*, 9(4), pp.50-61.
Leiner, B.M., Ruther, R.J. & Sastry, A.R., 1996. Goals and challenges of the DARPA GloMo program [global mobileinformation systems]. *Personal Communications, IEEE*, 3(6), pp.34-43.
Pawlikowski, K., 2003. Do Not Trust All Simulation Studies of Telecommunication Networks. In *International conference on information networking (ICOIN)*., 2003. Springer Berlin / Heidelberg.
Pawlikowski, K., Jeong, J. & R., L., 2002. On credibility of simulation studies of telecommunication networks. *Communications Magazine, IEEE*, 40(1), pp.132-39.
Sanchez, S.M., 2001. Output modeling: abc's of output analysis. In *WSC '01: Proceedings of the 33nd conference on Winter simulation*. Arlington, Virginia, 2001. IEEE Computer Society.
Stepanov, I. & Rothermel, K., 2008. On the impact of a more realistic physical layer on MANET simulations results. *Ad Hoc Netw.*, 6(1), pp.61-78.
Subbarao, M.W., 2000. *Mobile Ad Hoc Data Networks for Emergency Preparedness Telecommunications - Dynamic Power-Conscious Routing Concepts*. Interim project report. Gaithersburg, MD, USA: Wireless Communications Technologies Group, National Institute of Standards and Technology.
Wu, B., Chen, J., Wu, J. & Cardei, M., 2007. A Survey of Attacks and Countermeasures in Mobile Ad Hoc Networks. In *Signals and Communication Technology*. 1st ed. Springer USA. pp.103-35.