Performance of Wireless Network Simulators - A Case Study

Dalimir Orfanus
University of Paderborn
Faculty of Computer Science and Mathematics
33102 Paderborn, Germany
orfanus@upb.de

Johannes Lessmann
University of Paderborn
Faculty of Computer Science and Mathematics
33102 Paderborn, Germany
lessmann@upb.de

Peter Janacik
University of Paderborn
Faculty of Computer Science and Mathematics
33102 Paderborn, Germany
pjanacik@upb.de

Lazar Lachev
University of Paderborn
Faculty of Computer Science and Mathematics
33102 Paderborn, Germany
lachev@mail.upb.de

ABSTRACT

Designing protocols for wireless networks is a challenging task. Combined with the fact that such networks are often deployed for critical missions like forest fire detection in the WSN scenario or have to function properly and efficiently for an extended period of time, it is desirable to thoroughly test, analyze and evaluate newly developed communication protocols before deployment. In order to do this, simulations are a good compromise between cost/complexity and accuracy of the results. Since there are many simulators for wireless networks, it is often difficult to decide which one to choose. Therefore, we present a case study in which four common wireless network simulators were used to evaluate a well-known topology control protocol (SPAN). Within the case study, we describe the strengths and weaknesses of the examined network simulators: First, we evaluate the usability of the simulators in terms of different parts of the protocol developer's work process. Moreover, we also focus on the simulator's support for reusability and maintainability of simulation models by measuring particular model properties. For this purpose, we have proposed a model of quality for network simulators. The model of quality defines which properties of models to measure and how to interpret them. As opposed to other simulator comparisons, we do not focus on the correlation of the individual simulation results. Through this paper, we aim at providing a basis for finding an adequate simulator for a particular task.

Categories and Subject Descriptors

C.2 [**Computer-communication networks**]: Network Architecture and Design—*Wireless communication*; C.2 [**Computer-communication networks**]: Network Architecture and Design—*Network topology*

General Terms

Design, Performance

Keywords

J-Sim, OMNeT++, SPAN, ShoX, case study, maintainability, model of quality, model properties, network simulators, ns-2, reusability, wireless network

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1. INTRODUCTION

Typically, nodes in wireless networks, i.e. ad hoc and wireless sensor networks, cooperate to achieve a common goal like environmental monitoring, communication, etc. The unreliable channel between nodes, the possibility of node movement and network sizes of 100s or 1000s of nodes incur a high amount of complexity. Further, since wireless nodes are often resource-constrained, it is also generally not feasible to implement algorithms requiring a high amount of processing power or large memory footprint. All this makes designing protocols for wireless networks a challenging task. Combined with the fact that such networks are often deployed in scenarios which require reliable operation, it is inevitable to thoroughly test, analyze and evaluate protocol behavior before real-world deployment.

First there is the possibility of testbed implementation, to achieve this aim. While testbeds yield rather accurate results, there are the following drawbacks: (1) Hardware cost in the light of large deployment scenarios, (2) special issues involved with specific hardware, (3) unpracticability and infeasibility of this test method in large networks due to the immense complexity and (4) a lack of realistic environment with deployment-like propagation properties and network dynamics. Secondly, there is the possibility of wireless network simulation with a model of the physical world avoiding the above-described drawbacks. Nevertheless, there is the following disadvantage: the limited capability of models

to capture reality which implies a lower accuracy of simulation results. This disadvantage has its roots in the high cost involved with the amount of work that has to be put into making models precise and the constrained capabilities of simulation hardware on which the simulation has to be executed.

There is a large number of commercial and freely-available wireless network simulators with different strengths, weaknesses, foci and popularity. Therefore, choosing an adequate simulator for one's own needs is not a simple task. To provide a basis for finding an adequate simulator, in our case study, we implemented and evaluated the topology control protocol SPAN [3] with the simulators J-Sim, OMNeT++, ns-2, and ShoX. Our focus was not on the comparison of quality of simulation results, as in other comparison studies [15, 2], but we are focused on the usability level of simulators and quality of simulation models itself.

A simulator which supports seamless *reusability* and *maintainability* of simulation models is more desirable for a protocol designer and simulator user because it helps to decrease the overall development time and costs. Reusability stands for the property of being able to easily reuse already developed parts of the model from previous projects which in turn considerably decreases the overall development time of a new model. In the case of maintainability, we talk about the ability to easily interchange parts of the model, what is also desirable if we want to modify or improve current designs. These two qualities are mostly influenced by the simulator's architecture which should support reusability and easy maintainability in a straightforward way.

Reusability and maintainability of a simulation model are abstract and not tangible qualities which cannot be seen or even measured directly from the model. In this paper, we present our newly developed model of quality for network simulators which resembles this abstract terms into a set of easily measurable software properties.

The remainder of this paper is organized as follows. In Section 2, we introduce previous work related to our study (i.e. other simulator comparisons). In Section 3, we briefly review SPAN in order to be later able to refer to certain aspects of SPAN when it comes to outstanding or missing simulator features. Our quality model for reusability and maintainability is described in Section 4. Sections 5 and 6 are the main sections of this paper where the four simulators and our findings are discussed in detail. The paper closes with a summary in Section 7.

2. RELATED WORK

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 (description or comparison), the focus of the potential comparison (credibility of results, features, performance, etc.) and the level of detail. Table 1 provides a short overview.

Actually, all of the works listed in Table 1 consider different simulators or differ in their scope from this paper. The ones that are closest to our work are [8, 11, 10, 4, 1] as they include at least the three simulators J-Sim, OMNeT++ and ns-2, which we also consider. However, [8] examines their suitability for simulating the failure of critical infrastructures like electricity or telecommunication networks. This is very unrelated to what we present here. [11] and [4], although their list of simulators is huge, do not give a comparative study. Rather, they provide more or less unstructured descriptions of each of the simulators independently. In this paper, we aim at comparing simulators according to certain metrics. In [10], the authors give an overview about different issues in wireless sensor networks on a general basis. Only at the end of their work they present a table comparing the considered simulators according to their language, the available modules, and whether they have GUI support or not. Aside from the table, no detailed comparisons between the individual simulators are given.

Table 1: Overview of some previous network simulator comparisons

Paper	Type	Simulators	Focus
[20]	comparison	Opnet,ns-2	setup,result accuracy
[19]	case study	ns-2, Opnet, GloMoSim	architecture, results
[17]	comparison	ns-2, cnet, JNS, Opnet, AdventNet, NCTUns	features (limited)
[16]	case study	J-Sim, ns-2, SSFNet	scalability, speed, memory requirements
[8]	comparison	Opnet, ns-2, QualNet, OMNeT++, J-Sim, SSFNet	suitability for critical infrastructures
[14]	comparison	ns-2, Avrora, Opnet, GloMoSim	architecture, functionality, extensibility, resource requirements
[12]	comparison	ns-2, TOSSIM	architecture, components, models, visualization
[11]	description	GloMoSim, ns-2, DIANEmu, GTNetS, J-Sim, Jane, NAB, PDNS, OMNeT++, Opnet, QualNet, SWANS	overview
[10]	comparison	SSF, SWANS, J-Sim, NCTUns, ns-2, OMNeT++, Ptolemy, ATEMU, EmStar, SNAP, TOSSIM	models, type of visualization
[9]	description	OMNeT++, REAL, ns-2, C++Sim, cnet, SSFNet, CLASS, SMURPH	overview
[4]	description	ns-2, GloMoSim, Opnet, SensorSim, J-Sim, Sense, OMNeT++, Sidh, Sens, TOSSIM, ATEMU, Avrora, EmStar	overview
[1]	comparison	Opnet, ns-2, OMNeT++, SSFNet, QualNet, J-Sim, Totem	availability/credibility of models, usability
[15]	case study	Opnet, ns-2, testbed	accuracy of results
[2]	case study	Opnet, ns-2, GloMoSim	accuracy of results

The most detailed comparison is presented in [1]. The authors describe a variety of simulators including J-Sim, OMNeT++ and ns-2 according to the criteria listed in Figure 3. However, there are a number of important differences: (1) They consider all simulators from an industrial research point of view, hence, they focus on issues such as support for certain models (which are required for their project in mind), quality of human support, etc., which are rather less relevant for academic researchers. (2) They do not consider certain aspects which are important here, like installation issues, and discuss visualization and statistics only very briefly. (3) Their case study misses practical simulations and experiences: there are no practical experiences regarding installation, familiarization or implementation issues. This, however, is the focus of our case study.

3. SPAN

SPAN [3] is a topology control algorithm aiming at saving power without reducing the network capacity or loosing

connectivity. It does so by electing and constantly adjusting a set of active nodes called coordinators. The coordinators form a forwarding backbone of the underlying network while the non-coordinator nodes can switch their radios to sleep mode. From time to time the non-coordinator nodes check if they should become coordinators. Similarly, the coordinator nodes regularly check whether there are enough other coordinators in their neighborhood in which case they can go to sleep mode.

In [3], SPAN is implemented on top of the 802.11 MAC layer's power-saving mode. For the routing layer, the authors of SPAN chose a simple greedy geographic forwarding approach, similar to GPSR [13], but without perimeter routing around voids. Principally, each routing protocol would do as well. As SPAN has to interact with both routing and MAC layer, in [3] it is implemented in the logical link control layer of the ISO OSI stack. For our implementations in the case study, we will follow their example.

4. MODEL OF QUALITY FOR REUSABILITY AND MAINTABILITY

To evaluate which simulator offers better support for reusability and maintability, we have to measure qualities of designs which are developed by simulators. To measure and to interpret such abstract qualities we need a quality model. A quality model describes the way how qualities can be measured and interpreted. In our case, we modified the quality model for reusability and maintability from [**?**] where instead of Aspect-Oriented metrics suite we used Object-Oriented metric suite. Used metric suite is inspired by metric presented in [**?**] which we modified for the purposes of our four network simulators. The final model of quality is depicted on Figure 1. Given model of quality we have also formally specified in specification and modeling language AsmL [**?**].

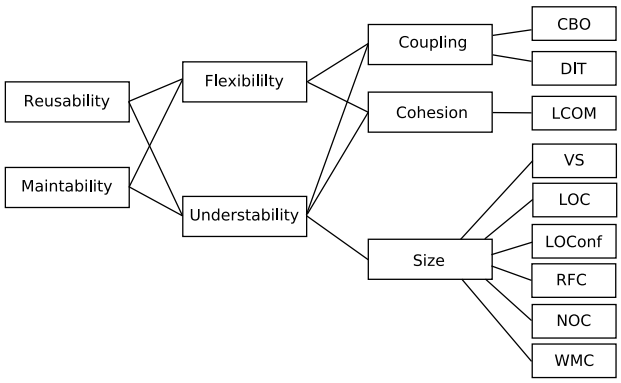

Figure 1: Model of quality

Reusing and maintenance involves the same cognitive tasks. It means that reusability and maintability are influenced by common factors namely *understanbility* and *flexibility*. Each of these factors is related to several *internal attributes*, in our case: (i) *Coupling* (ii) *Cohesion* and (iii) *Size*. There are various sets of software metrics to measure such attributes. In our quality model we used as follows:

4.1 Size metrics

Measures the size of the model and predicts how much of effort is needed to understand it.

Vocabulary size (VS): Number of components of which the model consists. Because all simulators are Object-Oriented, this is the number of classes of the model.

Lines of code (LOC): It counts the total number of non-empty lines from all classes.

Lines of configuration (LOConf): It measures the size of all configuration files needed by the model.

Number of children (NOC): It counts number of all direct children of a class.

Weighted methods per class (WMC): Measures overall complexity of methods per class. Access methods has zero complexity while other have 1.

4.2 Coupling metrics

They measure degree of dependency of a class to another class. Loosely coupled classes are easy to maintain and to reuse contrary to tightly coupled classes.

Depth of inheritance tree (DIT): It measures the maximum length from a node to the root of inheritance tree.

Coupling between objects (CBO): It counts number of classes to which an object coupled.

4.3 Cohesion metrics

Cohesion refers to the internal consistency within parts of the design. Classes with high cohesion are more robust, suitable for reuse and easy to maintain while opposite is less preferable for reuse.

Lack of cohesion in methods (LCOM): It measures the amount of methods which do not access the same instance attribute set.

5. CASE STUDY

For our case study, we selected four different network simulators to implement the wireless topology control protocol SPAN described in the previous section. The four simulators we chose were J-Sim [6], OMNeT++ [21], ns-2 [5] and a relative newcomer, ShoX [7]. The main reason why we chose the former three simulators is because of their popularity in the research community. While other simulators like Opnet [18] are also popular, for our case study we only considered simulators which are freely available.

As opposed to J-Sim, OMNeT++ and ns-2, which are well established, ShoX is comparably new. However, it is one of those simulators which offer a comprehensive graphical user interface for configuration, visualization and statistics. Additionally, it was developed from the beginning with *wireless* networks in mind, whereas most other popular simulators (including J-Sim, OMNeT++, ns-2 and Opnet) initially concentrated on *wired* networks and were only later extended to the wireless domain. Hence, for ShoX, there is no special wireless package as with the others, all functionality pertaining to wireless is an integral part of the software. This is why we chose to include ShoX in our case study. We were

interested to see in how far the focus on wireless instead of wired network simulation has any impact on ease of use and the learning curve.

The case study was performed by four people (the authors). To ensure fairness, only one of them did the actual installation and implementation task for all four simulators. This was to rule out any influences caused by potentially different programming proficiency or knowledge of computer network protocols. For all simulators, implementation of SPAN was done under Linux (Fedora 7) using the open-source platform Eclipse 3.3. The responsible student was not familiar with either of the four simulators before the case study. He had sufficient knowledge of popular programming languages like Java or C++, and fair knowledge of (wireless) computer networks. Before the start of the case study, he familiarized himself with SPAN, so that understanding problems with SPAN itself were not an issue during the implementation phase. During the case study itself, he carefully recorded each necessary step, questions that arose, efforts it took to find answers to them, features of the simulator that were helpful or confusing, and the times for the individual parts. His progress and experiences were discussed weekly among the authors.

The following section will introduce each of the four simulators from an architectural point of view. Then, we successively cover installation and documentation, implementation, visualization and statistics collection in more detail.

5.1 Overview

5.1.1 J-Sim

J-Sim (formerly JavaSim) is a network simulator written in Java. It is built according to the component-based software paradigm. In J-Sim terminology, this is called *autonomous component architecture* (ACA). Everything in J-Sim is a *component*: a node, a link, a protocol. Each component can be atomic or composed of other components. Connection between components is done through *ports*. Actually, there are three possible ways to connect ports: one-to-one, one-to-many, and many-to-many. On a more abstract level, J-Sim distinguishes two layers. The lower layer *Core Service Layer* (CSL) comprises every OSI layer from network to physical, the higher layer comprises the remaining OSI layers.

For wireless network simulations, J-Sim offers the Wireless Extension. Here, several components and their relationships are defined and extend the general CSL. Figure 2 gives an overview of the most important components. The only available MAC layer component in the Wireless Extension is 802.11 MAC.

When a node wants to send a message, it goes through 802.11 MAC which decides when the packet is sent to the WirelessPhy. The latter determines the nodes current position from the MobilityModel and adds that position, the current transmission power and the antenna gain to the MAC frame. The receiving node's WirelessPhy consults the RadioPropagationModel to decide if the packet should be passed to the MAC. The EnergyModel is a collection of five energy consumption values (radio states send, receive, idle and off). When the energy is depleted, no packets can be sent and received anymore.

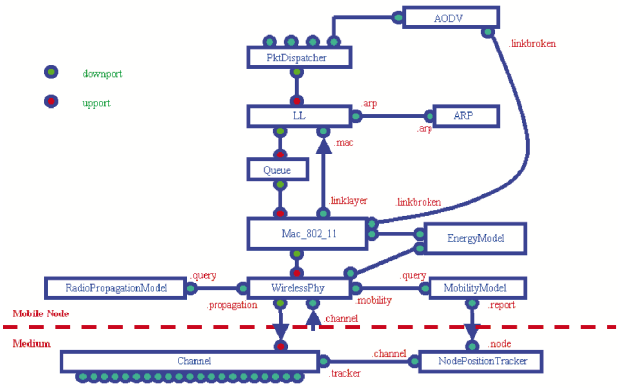

Figure 2: Overview of components in J-Sim's wireless extension.

5.1.2 OMNeT++

OMNeT++ is a simulation platform written in C++. Like J-Sim, it has a component-based, modular and extensible architecture. Thus, its structure shares many properties with J-Sim's. The basic entity in OMNeT++ is a module. Modules can be composed of submodules or they can be atomic. Only atomic modules capture the actual behavior. Modules communicate with each other via messages through *gates*. Gates are linked to each other using *connections*. A connection can be associated with a propagation delay, error rate and data rate. Unlike J-Sim's ports, gates in OMNeT++ support only one-to-one communication.

Regarding simulation of wireless ad hoc networks, OMNeT++ relies on external extensions. The two most prominent ones are the INET Framework (IF) and the Mobility Framework (MF). While the latter is an extension explicitly designed for mobile ad hoc networks we chose it for our case study.

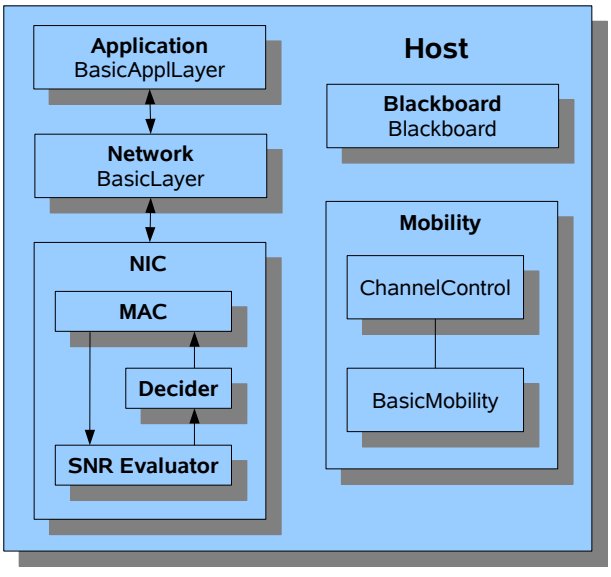

Figure 3: Overview of the basic modules in OMNeT++/(INET Framework).

Figure 3 depicts the structure of OMNeT++/IF. Aside from the most important OSI layers, OMNeT++/IF provides two modules called blackboard and mobility. A blackboard is used to share cross-layer data. The mobility part is responsible for providing and updating a node's current position and establishing communication channels. MAC and PHY layers are composed into a single NIC (network interface card) module. The physical layer is split into a module which determines SNR characteristics and another one responsible for deciding whether a packet can be passed upwards.

5.1.3 ns-2

The network simulator ns-2 is based on two languages: an object-oriented simulator, written in C++, and an OTcl (an object-oriented extension of Tcl) interpreter to execute user's command scripts. There are two class hierarchies: a compiled C++ one (which captures the protocol behavior) and an interpreted OTcl one for binding to the OTcl scenario configuration script.

Ns-2 offers a reduced OSI layer model in which the presentation and session layers are left out. For wireless network simulations, ns-2 offers a variety of features. It has an energy model, and both, traffic and movement patterns, can be easily generated. However, as opposed to the other three candidates, traffic and mobility are typically produced before the actual simulation start and are not so much an integral part of ns-2's architecture.

5.1.4 ShoX

ShoX is an object-oriented network simulator written in Java, which was targeted at wireless networks from the beginning. By default, its architecture follows the OSI seven-layer model, although only five of them are present by default. However, all layers are derived from an abstract superclass and are defined by LayerType objects. Hence, it is straightforward to include additional layers at any position in the stack for special purpose simulations. ShoX does not use components as e.g. J-Sim or OMNeT++. Rather, protocols, energy management, propagation or mobility models, etc. are all derived from abstract super-classes which define the minimum interface and functionality. The different entities in ShoX communicate through *events*. Devices are special kinds of components of a node like the network interface card, the power manager, the CPU or attached sensors.

In addition to the abstract OSI layer classes, there is a special "layer" called AirModule. Here, all channel related issues are handled (e.g. signal interference). PhysicalModel and InterferenceHandler of ShoX resemble the SNR Evaluator and Decider in OMNeT++. As Opposed to OMNeT++, forward error correction is handled by the actual layer implementations, which appears to more resemble reality.

Like J-Sim and ns-2, ShoX has an energy manager component. However, in ShoX, the energy manager is far more advanced making use of the concept of a device: different devices can be registered as power suppliers (e.g. solar panel) or power consumers (e.g. CPU, sensors).

5.2 Installation

5.2.1 J-Sim

Once J-Sim is downloaded, it can be easily imported into Eclipse using Eclipse's "Java Project from Existing Ant Buildfile". However, some additional java archives for XML handling (jaxp, xalan and crimson) must be installed before J-Sim can be executed. The whole installation and configuration process took approximately 1,5 days, mainly because of the JVM problems.

5.2.2 OMNeT++

OMNeT++ (3.3) is installed using configure and make scripts. Before installing OMNeT++, the two additional packages Tcl/Tk and BLT (set of new commands and widgets) must be installed. Even though BLT was already installed on our system, it was somehow not found by the installation script. Wireless extensions are installed using command line make commands.

The time it took for installing OMNeT++ and importing to Eclipse was approximately three days. Some of the delay was caused by a "problem" with BLT. Another issue was to figure out how to integrate the IF with OMNeT++ (it slightly changes the build process but that is not documented well).

5.2.3 ns-2

There are basically two ways to obtain ns-2: by downloading the all-in-one package or only selected components and libraries. Unfortunately, each time the user code is modified, ns-2 itself will be recompiled. Our solution to this problem was to compile our code into a separate shared library and link that to the ns-2 kernel. The lengthy ns-allinone installation attempt, the manual selection of packages, and the compilation environment setup made installing ns-2 considerably more time-consuming than J-Sim and OMNeT++.

5.2.4 ShoX

ShoX can be downloaded as a source package. However, we followed the recommendation on the website to instead directly use the more recent CVS version, since the release version (0.2) is rather outdated. Using Eclipse's "Projects from CVS", it is principally straightforward to import the CVS code into the tool. Unfortunately, no documentation is provided on the website on how to configure CVS, hence, the corresponding Sourceforge documentation must be consulted. After the setup in Eclipse, ShoX is started through Eclipse's run dialog. Despite the fact that a sufficiently detailed documentation is missing, trying to figure out the right configuration took us approximately half a day.

5.3 Implementation and Documentation

5.3.1 J-Sim

J-Sim offers good introductory material with overviews and examples for small scenarios. However, it lacks a comprehensive manual. Several more specific questions remain undocumented, for example how to send broadcast. Also, we did not find any hint as to how a new packet is to be defined. The problem was that the MAC layer, which had to communicate with SPAN (see Section 3), assumed out SpanPacket to have certain fields and parameters which were nowhere clearly expressed, but led to erroneous behavior nonetheless.

J-Sim uses Tcl for configuration of simulation scenarios. This requires a certain learning overhead. The binding between Java and Tcl (to be able to access Java objects and methods from Tcl) is pretty intuitive. There is also a graphical editor for the Tcl configuration files called gEditor.

The familiarization with the configuration part took us around two days. Another three days were spent to solve the problems mentioned above. The implementation itself, simulator-specific problems aside, took ten days. J-Sim offers both AODV and GPSR, therefore testing of SPAN was quite simple.

5.3.2 OMNeT++

OMNeT++ has a well-written fairly large user manual while IF has only an API documentation. OMNeT++ is very complex, thus careful consultation of the available documents is needed. To understand and run small examples took us approximately three days. Scenario configuration is done in so-called network description files.

One major drawback of OMNeT++ is that it does not have an energy model. Thus, while OMNeT++ certainly is a feature-rich and powerful simulation platform, it was not possible to implement and test SPAN completely. Another issue was finding a suitable routing protocol for testing. While there is an AODV implementation listed on the website, the referenced page refused to load. Whereas the MF includes AODV, the IF does not and GPSR is not available with OMNeT++. Hence, we decided to use DYMO which integrates well with IF. These issues, especially the search for a suitable MAC and AODV implementation added another two days to our simulator-specific overhead time. Implementation itself (to the extent possible) lasted nine days.

5.3.3 ns-2

From all the four simulators we tested, ns-2 clearly has the steepest learning curve, even though its documentation is comprehensive. For ns-2, there is a manual which is regularly updated. Further, there is an API for the C++ and OTcl classes (although the latter are not explained very thoroughly). Still, working with ns-2 requires learning many concepts. This starts with the object-oriented version of Tcl called OTcl which is used for scenario configuration. It also includes the structure of the configuration environment itself. This is unfortunately not as intuitive as with other simulators. We needed approximately eight days to become familiar enough with the complete environment.

In ns-2, the not very easy-to-use OTcl handles the task of describing the simulation scenario. To construct a binding between OTcl and the actual C++ classes, each C++ class must be accompanied by a corresponding OTcl class, causing a considerable overhead. For the implementation itself, we needed about 3.5 days. The short length of this timespan is due to the fact that we simply had to adapt our C++ classes from the ones we already wrote for OMNeT++. One of the major advantages of ns-2 is the huge pool of available features, offering a large number of external protocols already implemented.

5.3.4 ShoX

Although missing a user manual, ShoX provides an API documentation which contains explanations for most of the classes and their members. Getting familiar with ShoX took us about two days.

Scenario generation in ShoX is done through its GUI. Unlike in gEditor or gNED, there are no modules and links to be drawn. The configuration UI in ShoX is a wizard leading through the necessary steps for all needed elements. It appears that ShoX focuses on ease of use, which in some cases (e.g. configuration) reduces the amount of available possibilities. However, for our chosen protocol, SPAN, the approach is completely sufficient. We needed three days to implement SPAN. Again, we could adopt a lot of code from our J-Sim classes. Unfortunately, while the energy management of ShoX is the most advanced among all four simulators, its 802.11 MAC does not support the power-save mode.

5.4 Visualization and Statistics

5.4.1 J-Sim

J-Sim has no tool for network visualization itself. However, it allows generating trace files which conform to ns-2's nam (network animator) format. To plot simulation statistics, a special plot component is provided. Because of this concept, only statistic values *over time* can be output. Other x-axis values are not possible. Also, the plot component is not able to write the received data to a file. If this is desired, the user must do it himself.

5.4.2 OMNeT++

OMNeT++ is the only simulator with online visualization. Hence, users can pause the simulation and inspect or even directly change values in the models. It is also possible to change a node's appearance (color, size, shape, etc.) to reflect an inner state which the user wants to visualize. Statistics can be written to a trace file and displayed with external but commonly available tools like prove.

5.4.3 ns-2

In order to visualize network behavior in ns-2, one must first of all call two scripts: one to generate a traffic trace file and another one to create a movement trace file. These two trace files can then be referenced as an input in the Tcl configuration for the actual simulation process (i.e. the network is simulated with the specified traffic and movement patterns). The simulation in turn generates a log file which can then be visualized using ns-2's network animator (nam). nam is similar to OMNeT++ in the way that it can visualize not only nodes, links, movements, packets, etc. but also changing node states by adapting the graphical appearance of the node. However, the possibilities in nam regarding a dynamic change of appearance are rather limited.

For plotting statistics, a function in the OTcl configuration file is used, which is called initially at simulation start time (or any other time), and which periodically calls itself. In each execution of this function, some statistical values may be written to a file. After the simulation end, an appropriate external tool (we used xgraph) is used for plotting the data.

5.4.4 ShoX

Regarding visualization and statistics, ShoX is the most powerful and integrated simulation platform among the four candidates. It includes both, a network and a statistics visualizer, in the same GUI (from which also the configuration is done and the simulation started). Like OMNeT++ and nam, ShoX can visualize node movements, links and packets. Regarding node state representation, the mapping between the node state (which is logged in the simulation log file) and the desired graphical representation of that state in terms of node color, size, shape, labels, border color and border width

can be changed retroactively and even while the visualization is running. In addition to the node state visualization, ShoX supports visualizing link states by changing the link appearance in the same fashion. ShoX also offers a statistics chart generation with three different chart types.

6. RESULTS

On the Figures 4 and 5 are summarized results of our studies. As we can see there is no clear winner in all areas. J-Sim is attractive because of its flexible component-based architecture while OMNeT++ shined at GUI support which helps while developing one's own protocol. ns-2 profits from the large number of available models which can be taken to compare own protocols to others once the former are ready. ShoX is the youngest simulator but is outstanding when it comes to visualization. Concerning the amount of effort it takes to become familiar with a simulator, we observed a clear order from ns-2, over OMNeT++ to J-Sim and ShoX. While we think this is on the one hand due to architectural decisions, part of it stems from the feature richness or ns-2 or OMNeT++, especially regarding their scenario configuration capabilities.

Aspect	J-Sim	OMNeT++	ns-2	ShoX
energy model	✔	–	✔	✔
802.11 power-save	✔	–	✔	–
SPAN completed	✔	–	✔	–
AODV	✔	✔	✔	✔
DSR	–	–	✔	–
GPSR	✔	–	✔	✔
visualization	nam trace file, no own tool	online with model inspection, to go back, simulation must be repeated	trace file, can be viewed with nam	trace file, internal viewer
statistics	online plot, exporting to file must be done by user	trace file, can be displayed with plove	log file, can be displayed with xgraph	statistics file, internal viewer or export to gnuplot
strengths	+ flexibility + Java based	+ maturity + model inspection + GUI support	+ model base + user base	+ GUI support + visualization + architecture
weaknesses	- GUI support - visualization capabilities	- energy model - MAC competitors	- OTcl - architecture	- documentation - lack of models

Figure 4: Simulator feature matrix.

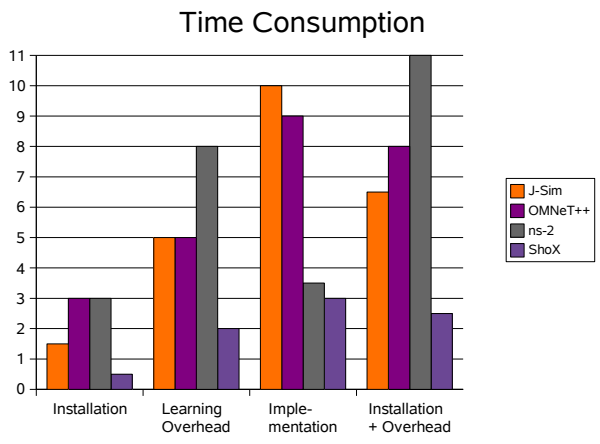

Figure 5: Comparison of consumed time.

On the Figure 6 we can see results of used metrics to measure reusability and maintability which were introduced in Section 4. In the Figure we omit metrics which gave null or zero values. Considering the size of the model, ShoX has the best values while other three simulators have models of similar size. In the case of coupling, we got better results with OMNeT++ and ns-2 because their vocabulary is smaller. The worst cohesion has the model from J-Sim. The reason is, that the configuration of interconnection between components is located inside classes as opposite to other simulators.

	J-Sim	OMNeT++	ns-2	ShoX
VS	6	5	5	6
LOC	873	942	1037	791
LOConf	255	253	180	76
WMC	44	46	47	42
CBO	9	8	8	9
LCOM	108	6	7	2

Figure 6: Measured values of the quality model

7. CONCLUSION

In this paper, we have presented the results of a case study in which we compared the wireless network simulators J-Sim, OMNeT++, ns-2 and ShoX by implementing a simple topology control algorithm called SPAN. We evaluated strengths and weaknesses of each simulator with respect to installation, implementation issues and visualization capabilities. To compare which simulator offers better support for reusability and maintability, we have proposed model of quality to measure them. We have seen that none of the four simulators is the single best candidate in all areas. Rather, each simulator has fields where it is stronger than the others. Each of them also showed areas of particular weakness compared to the other candidates.

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