Review of Simulators for Wireless Mesh Networks

Piotr Owczarek and Piotr Zwierzykowski

Faculty of Electronics and Telecommunications, Poznan University of Technology, Poznan, Poland

Abstract—The research of computer networks construction of models that reflect the current audited environment to carry out practical research is extremely difficult and often involves significant costs. Hence, the popularity of simulation tools that help developers to determine as early as at the stage of the simulation whether a given solution can be deployed in a real network. However, over time many different simulation tools have been developed, each with different characteristics, different uses, different strengths and weaknesses. It is the task of the researcher then to select, before starting the actual research, one of the available simulators in accordance with the needs and adopted criteria of evaluation. In the article the authors present issues related to the simulation tools and the main advantages of simulation as well as their drawbacks. To help researchers select an appropriate simulation environment, the authors present statistical information gathered during a literature survey of a number of research articles from the most popular publishers in which the selected simulators were used in initial system design.

Keywords—simulators, wireless mesh networks.

1. Introduction

Wireless Mesh Networks (WMNs) is one of the key technologies for current Wireless Networks. It has become more popular over the past years. WMN can be an answer for the last mile problem, a solution for rugged terrains, developing regions and countries [1]. The networks equally behave well in education, hospitality management, car industries, etc. [2]. They are also promising technologies for military forces to quickly build wireless networks over, for example, the battlefield. Just as in the case of any computer networks, also in the case of WMN we need to develop routing metrics and protocols which would suit all needs of potential applications [3], [4]. Every such solution, before it can be used in real environment, should be checked by researchers in some test environments. It is not trivial to choose a proper tool for testing and simulating different network behavior [5], therefore in this article the authors attempt to facilitate a choice of them.

The paper is organized as follows. In Section 2, main methods used in the evaluation process of routing protocols and metrics and main advantages and drawbacks of using simulators are presented. Section 3 surveys network simulators indicating their advantages and disadvantages. In Section 4, the authors present the results of a survey based on published articles carried out in the area of WMN network

and aim to determine the popularity of individual simulators. Section 5 concludes the paper containing both an attempt to answer the question of what criteria to follow when choosing a simulation environment.

2. Simulation Tools

2.1. Main Evaluation Methods of Routing Protocols

Typically, the development process is divided into two phases: the evaluation by means of quality tools and the subsequent prototype testing in a close-to-real environment test beds.

In the case of Wireless Mesh Networks, as compared to traditional wireless networks, there is an additional challenge, due to the structure of network, stationary nodes roles as well as clients mobility and roles.

It is also worthwhile to mention that there are some specific characteristics of Wireless Mesh Networks that provide additional conditions for simulating them, such as [6]:

- wireless – what implicit limited transmission rates and high loss rate;

- multi-hop – means that traffic is forwarded through nodes that are not in direct range of the node that generates it;

- redundancy – the nature of WMN implies redundant links in the wireless backbone of network;

- mobility – while backbone nodes are mostly stationary, clients of the network should be treated in simulation models as mobile;

- dynamics – because of the self-configuring and self-healing ability of WMN one should consider smooth changes in the structure of the network; the network is established in a very spontaneous way;

- infrastructure – dual type of nodes in network should be considered - mobile clients versus stationary nodes;

- integration – the duality of structure also in roles that nodes play in network - lightweight clients can join the WMN network without serving any routing services.

Researchers that need to evaluate a routing protocol or routing metric for WMN have to choose a evaluation model. We can choose from different types of evaluation processes [6], [7]:

- **Theoretical analysis** – in that process a mathematical models to evaluate network performance is used. The most commonly used mechanism is queuing theory. It is a very difficult means of development, mathematical formulas can get very complex and, thus, can consume a large amount of time. What is more, there are no dedicated mathematical tools to provide such analyses. Nevertheless, a mathematical analysis is often the first step of the development process.

- **Simulations** – with special tools the researcher is capable of modeling virtual environment to help verify the general idea, detailed parameters and solutions, or to compare proposed solutions. Simulations are particularly useful for studying highly distributed networks such as Wireless Mesh Networks or Wireless Sensor Networks. In this way one can discover behavior in such networks under a change in some parameters, while others remain fixed. Additionally, simulation base studies are very flexible with low cost.

- **Emulation** – it is a hybrid study environment that consists of two parts - real and simulated. It depends on the researcher's goal which element is real and which simulated. Emulation has one important advantage – any results from such tests are more realistic as any experiment part because it is a real working part.

- **Virtualization** – general idea of virtualization is to provide virtual environment in which hosts to conduct experiments are run. Nowadays, virtualization is becoming quite simple and inexpensive, so it becomes more and more widely used. It is actually rather easier to use existing hosts and install virtual hosts on it than to build a quite new infrastructure that consists of many physical machines. It can vary to what degree virtualization can be used – it can be full with virtual hosts, virtual operating systems and all network equipment or as virtual instances or virtualized only as a part (for example only client hosts). Virtualization can offer good tools for evaluating communication protocols – it is possible to provide multiple virtual hosts on a single physical machine, thus the experiments cost can be minimized.

- **Real test-beds** – it is a development process based on a prototype implementation that should produce the most realistic results. By using it, the researcher can simply transfer their ideas to the real world, though the influence from environment should be also considered as it can significantly affect conducted experiments.

2.2. Advantages and Drawbacks of the Use of Simulators

Using simulation tools for conducting processes of testing network routing protocols, or any other researcher's ideas connected with networks, has many advantages. The two most important are the low cost of the whole process and the ease of maintaining of a simulation [8].

In the case of testing a new idea, there is almost always a need for rebuilding a number of modules, redesigning the model, etc. While using a real test-bed or a prototype that is part of the process can be expensive both in financial terms and the time involved. Simulations take the building/rebuilding phase out of the loop by using the model already created in the design phase. Most of the time, the simulation is cheaper and faster than performing multiple tests of the design each time in real test-bed [5].

The other important advantage is the ease of maintaining a simulation. A simulation can be repeated as often as it is needed with repeatable results probability close to certainty. Additionally, researchers have full control over the simulation process at any of its stage. A scenario preparation for simulation purposes is easy to create and collecting of results is also easy to perform.

There are also simulations disadvantages as well [9]. It is worth mentioning lack of existing standards in that area (i.e., no standardized tools which would generate results in a way that would be easy to compare with others), such a dependence results from the implementation of simulation tools or the fact that instead of the actual physical layer there is an abstract software layer, which can lead to differences between simulation results and those obtained in real world.

Table 1 presents the main advantages and drawbacks of the use of simulation tools.

Table 1
Advantages and drawbacks of the use of simulators

Advantages
• Easy to expand network topologies due to simulation applications high scalability
• Simulation process is easy to maintain
• It is the most common way of developing and testing new routing protocols
• Testing cost relatively small
• Results have high repeatability
• Full control of simulation process
• Easy process of scenario preparing and data collecting

Drawbacks
• There is no standardized simulation tool that would allow to compare simulation results between different projects
• Results can differ from real world because of abstracted PHY layer modeling
• Results can depend on a particular implementation of simulation software

3. Simulation Tools for WMN

3.1. Description of Selected Simulation Tools for WMN

Network Simulator 2 (NS-2) is an open source, discrete-event network simulator [10] that provides support for a simulation of main protocols, routing, multicast protocols for wired and wireless networks. NS-2 is the most popular simulator tool among researchers and becomes de-facto a standard for simulators. It was developed in 1989 as a variant of REAL Network Simulator. Based on C++ and OTcl, NS-2 was continuously developed till the end of 2011. The simulation environment can be run on a number of operating systems, i.e., Linux, Windows, OS X, Solaris, etc. As a module for supporting Wireless Mesh Networks, there is a library called WiMsh, additionally there is also a framework for NS-2, called Multi-routing-protocol Simulating Framework, proposed by researchers from Southeast University of China in which WMN is also adopted. NS-2 provides support for OSI Layers except the presentation and session layers. The simulator

Fig. 1. NS-2 NetAnimator example.

Fig. 2. Visual Network Simulator.

has a complex structure that makes writing new modules a hard task for researchers because it requires a simulator good knowledge. Additionally, because of the application of two different languages (C++ and object oriented OTcl), a creation of even a simple scenario can become a complicated job. Thanks to the NS2 users community, there are many additional resources like modules for specific scenarios, topology generators, or GUI tools. The most popular tools are: topology generators (i.e., Inet Topology Generator [11], GT-ITM [12], or Tiers Topology Generator [13]), tools to visualise results of simulations (i.e. Nam [14], Fig. 1), or applications for graphic creation of NS-2 scripts – Extended NamEditor [15]. The user interface implemented in NS-2 is based on the command line tool and operation on source files. There is no integrated GUI, but as an addition one can use many tools proposed by the large community that provides such a functionality, for example, Visual Network Simulator (Fig. 2).

Network Simulator 3 (NS-3) is also an open source (licensed under GNU GPL), discrete-event network simulator, released in 2006 [16] that is still under development. NS-3 should be rather considered as a replacement than an extension to the previously described NS-2 [17]. The simulation environment is based on C++ and Phyton and can run under most of modern operating systems. NS-3 has a possibility to generate pcap traces of simulated models, so researchers can easily debug output with standard tools such a Wireshark [18]. NS-3 includes a radio energy model for simulating energy consumption and has a set of classes for simulating 802.11s mesh networks [19]. Additionally, there is also a number of external tools provided by the NS-3 community. The user interface for NS-3 is command line based, but there are also some additional tools for NS-3
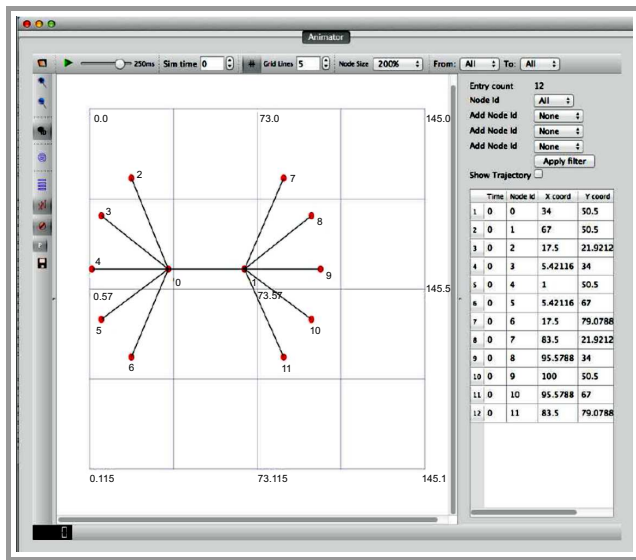

Fig. 3. Example of NS3 GUI.
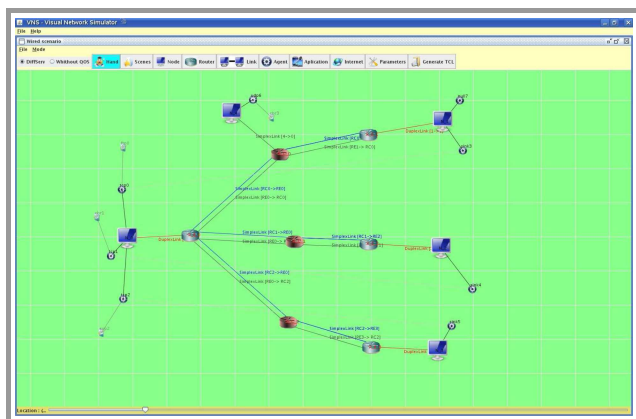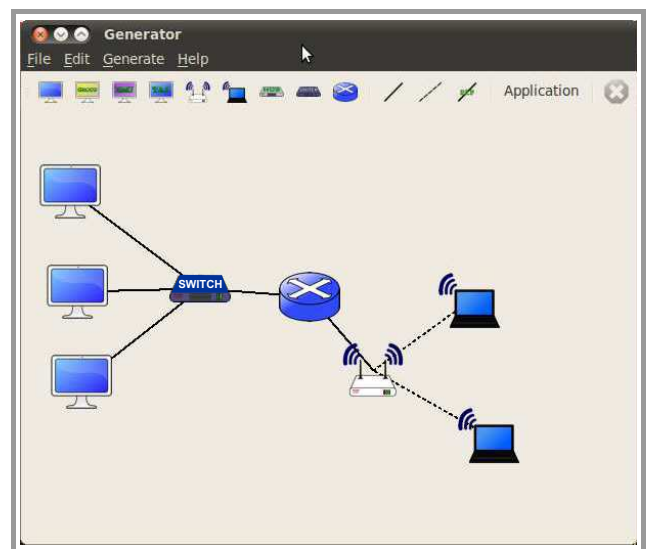
available that provide GUI (Fig. 3), such as NetAnim [15] for tracing results of tests or PyViz [20] (Fig. 4) for live simulation visualization.
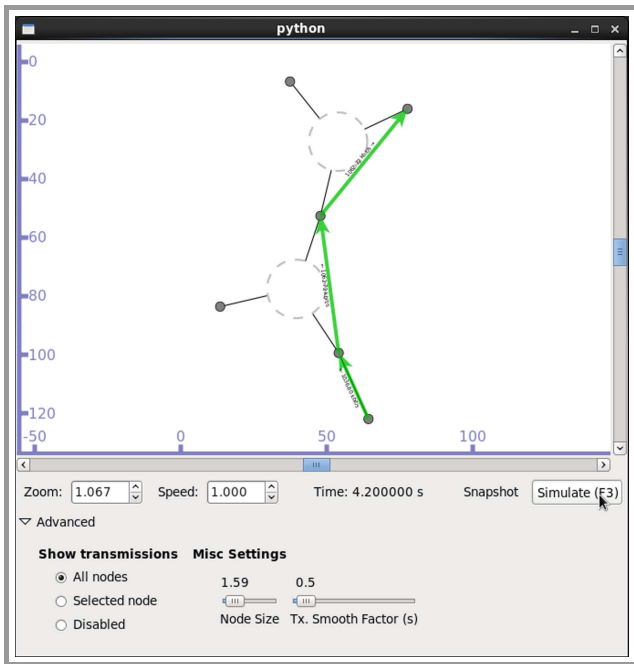
Fig. 4. PyViz application example.

OMNET++ is a component based, modular, open architecture event simulator [21], licensed under the modified GNU Public License called Academic Public License, which means that it is free to use for educational and non-commerce purposes. The interface of OMNET++ is based on C++ equipped with a GUI based on the Eclipse environ-
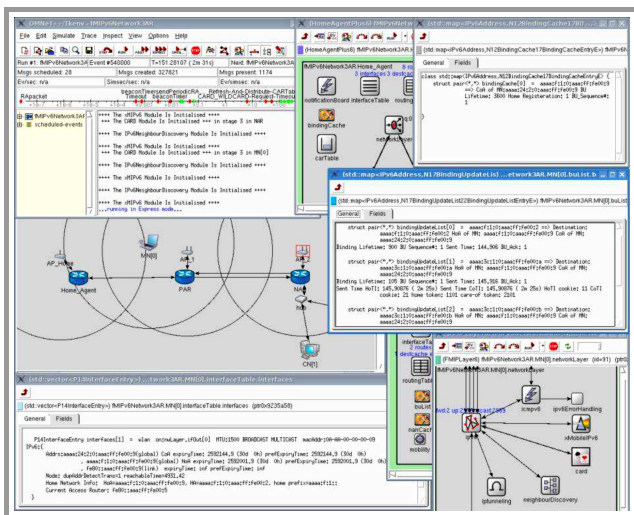

Fig. 5. Example of OMNET GUI.

ment (Fig. 5). The simulator runs on Linux, MacOS and Windows systems. It supports the simulating process of Wireless Mesh Networks – there is a library named Virtual Mesh [22] that can also be used as an emulation framework. Additionally, for simulating mobile and fixed wireless networks, there has been developed a whole modeling framework called MiXiM [23]. Many tools and utilities have been developed by OMNET programmers and com-

munity members to maintain simulations results or scenario generation. There are also available extensions for writing code in different programming languages – for example in Java, most of them are available to download for free from OMNET++ Web pages. The documentation and community forum provides a good level of support, which makes this tool quite user-friendly even for beginners.

OPNET is a commercial discrete-event simulator, first proposed in 1986 and developed by MIT in 1987 [24]. The interface of OPNET is C++ based. The dual-purpose simulator provides an environment for: designing protocols and testing scenarios in realistic environments. OPNET Modeler can use topologies created manually as well as those imported or selected from the pool of predefined ones. There is a vast number of protocol models available in the program suite. For a wireless networks simulation, OMNET uses an extension called OPNET Modeler Wireless Suite [25]. Modeler has an advanced GUI interface used for creating models, simulation execution and data
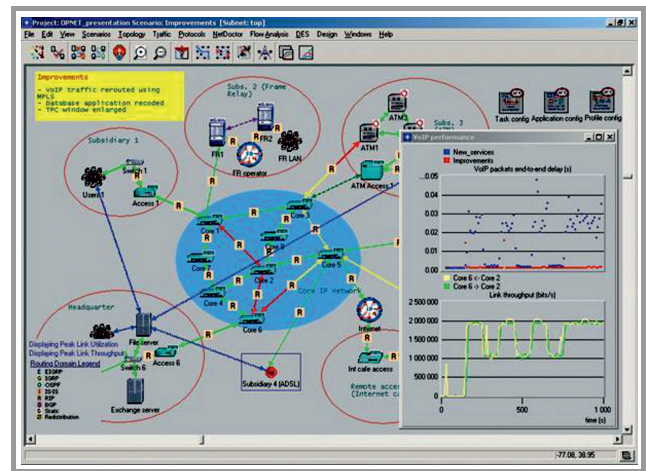

Fig. 6. OPNET GUI example.

analysis (Fig. 6). OPNET Modeler provides a good manual, there is also a dedicated technical support for a commercial use of simulator. There are also specialized training sessions provided my the manufacturer to help you use the software. The system can be run under Windows or Linux.

Global Mobile Information System Simulator (GloMoSim) is a simulator framework used for large scale wireless networks [26], it provides a functionality similar to QualNet that is however truncated from some additional features. There is no GUI provided by GloMoSim and the available documentation is not so in-depth. GloMoSim is also a C++ based simulator (with Parsec for maintaining parallel operations), distributed under Open Source License. Support for Wireless Mesh Networks is not in such a wide range as it is in the case of QualNet, though the simulator is capable of simulating networks that contain thousands of nodes. The simulator offers a possibility to install external GUI tools for the visualiza-

Table 2

Comparison of network simulation tools

	NS2	NS3	OPNET	OMNET++	QualNet	GloMoSim	JSim
Interface	C++/OTcl	C++/Python	C/C++	C++	Parsec	Parsec (C)	Java
Graphical Support	No	Limited	Yes	Yes	Yes	Limited	Yes
Parallelism	No	Yes	Yes	Yes	Yes	Yes	Yes
Scalability	Small	Large	Medium	Large	Very large	Large	Small
Documentation and user support	Excellent	Excellent	Excellent	Good	Good	Poor	Poor
Extendibility	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Emulation	Limited	Yes	Not direct	Limited	Yes	Not direct	Yes

tion of results, but no tool for designing tests. Despite these drawbacks, GloMoSim is quite a popular tool among researchers.

QualNet is a network simulator developed by Scalable Network Technologies [27]. In fact, it is GloMoSim simulator commercial version. It is a powerful, ultra high fidelity network simulator. Its interface is based on C++. Almost all functions of that tool are available from the GUI level, which makes learning the application process quite easy and lets the researcher focus on simulation process goals (Fig. 7). QualNet also has the support for Wireless Mesh Networks, there are some external models for these type of networks available for download. QualNet runs under Linux and on Windows.
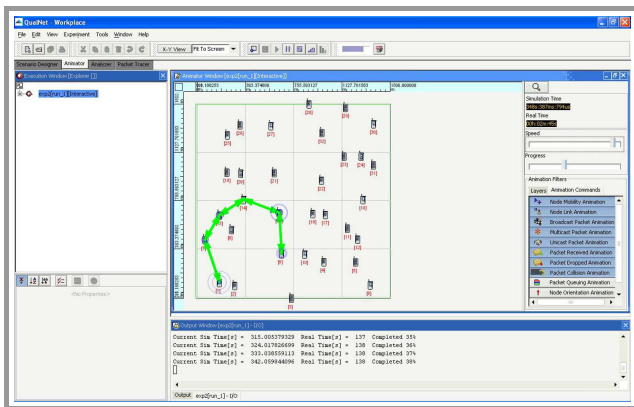

Fig. 7. Example of QualNet GUI.

J-Sim, formerly known as JavaSim, is a Java based simulation system for building and analysing numeric models [28]. It is distributed under an OpenSource License and can be installed either on Linux or Windows machines. With the external tool called gEditor (Fig. 8) the user is provided with the Graphical User Interface that makes it very easy to build network models and conduct simulations. For a wireless networks simulation, J-Sim has a wireless extension but support for Wireless Mesh Networks is not available from the developers of J-Sim, though can be found in the community resources through additional
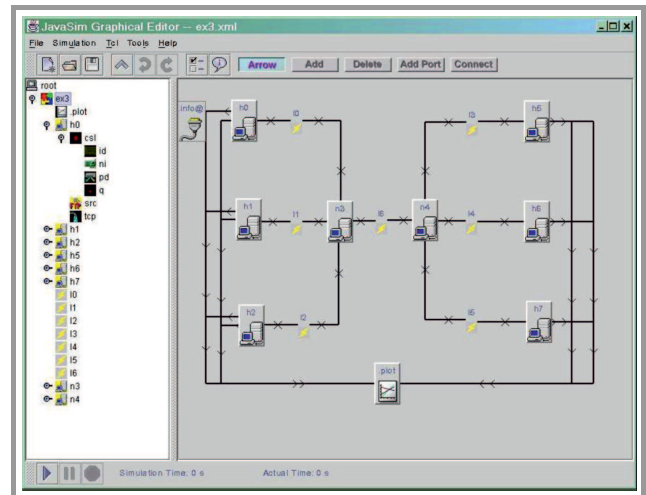

Fig. 8. J-Sim gEditor application example.

libraries. The simulator has a good documentation with examples for some small scenarios though the details level is quite low.

3.2. A Network Simulation Tools Comparison

It is obvious that there is no universal simulation tool that would fit all needs. It is also true that modeling everything in a complete simulation mode is simply unattainable. There are different features that distinguish a particular simulation software for specific applications (Table 2). There are many literature studies that compare different aspects of the simulator software, i.e. [29], [30], but at the end it is the researcher's choice which one they would use.

3.3. Main Criteria for the Simulation Tools Selection

There is a number of criteria that are used to determine whether or not a particular simulation tool is to be selected and is most appropriate for a given purpose. It can distinguish the following exemplary criteria:

- general capabilities: flexibility, available models, reusability, devoted to specific problem or class of problems, orders of magnitude for simulation size;

Table 3
The use of selected simulators in publications related to wireless networks

	2000–2013											
	IEEE			Springer			Wiley			Elsevier		
	Mesh	Ad-hoc	Sensor	Mesh	Ad-hoc	Sensor	Mesh	Ad-hoc	Sensor	Mesh	Ad-hoc	Sensor
ns-2	135	307	300	76	579	128	14	70	65	105	716	382
ns-3	15	16	9	7	23	4	4	1	2	8	50	34
OPNET	43	103	86	36	122	61	9	21	10	56	186	128
OMNET++	4	1	8	17	53	48	7	5	18	15	82	123
QualNet	17	50	32	5	68	16	6	17	6	17	103	42
GloMoSim	5	46	13	1	115	9	1	16	10	7	125	30
j-sim	2	6	14	0	4	18	0	0	7	1	9	11

- hardware/software considerations, i.e., operating system, compilers, specific hardware needs;

- graphical facilities;

- statistical features;

- ease of use, documentation, support;

- output reports and plots;

- popularity.

4. Popularity of Simulation Tools

Choosing a simulation tool that would meet a project's design and functional requirements can be a tough work. It is also the issue which the authors have to solve. To form an opinion on the available simulators popularity, the authors conducted a literature survey of simulators most frequently used by researchers. The survey was based on all articles available through search engines of IEEE, Elsevier, Wiley and Springer publishing houses. The authors searched for articles published between the years 2000–2013 in the field of Wireless Sensor Networks (WSN), Wireless Ad-hoc Networks and Wireless Mesh Networks (Table 3).
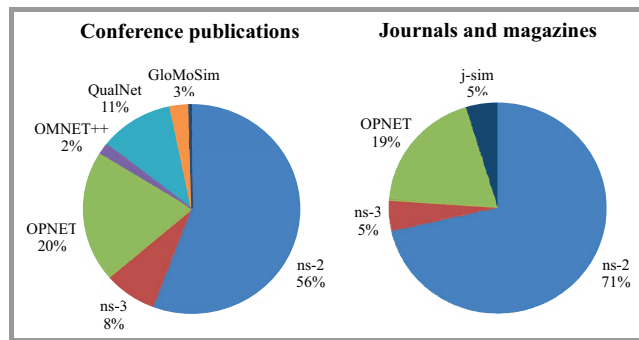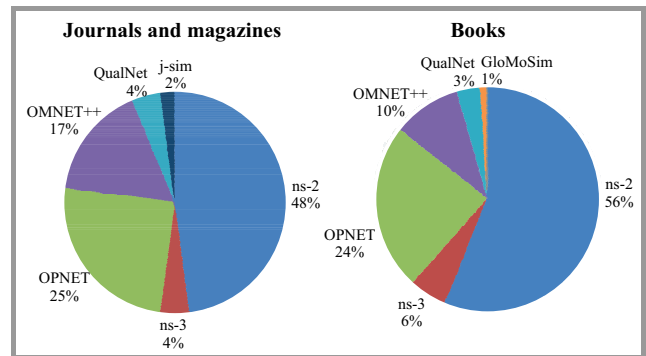

Fig. 11. Popularity of WMN simulators by Springer.

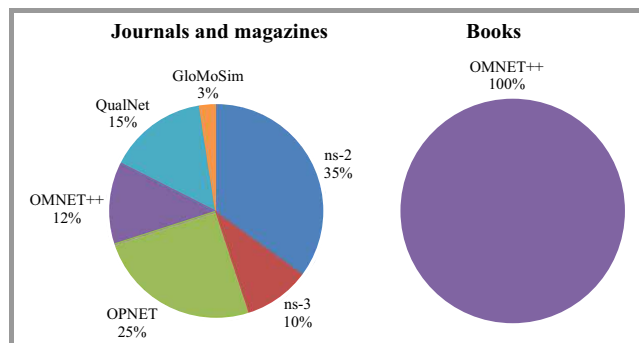*Fig. 9.* Popularity of WMN simulators by IEEE.
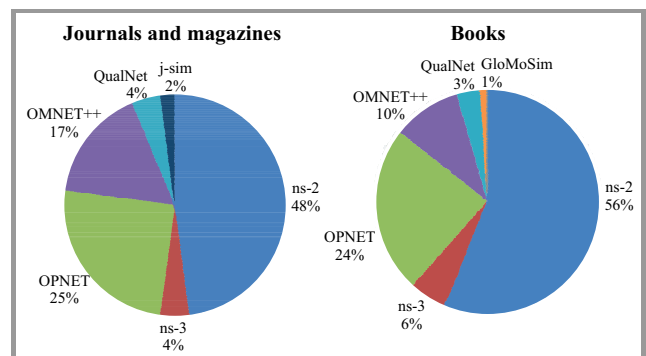

Fig. 12. Popularity of WMN simulators by Elsevier.

Fig. 10. Popularity of WMN simulators by Wiley.

The results analysis show that NS-2 is still the most popular simulation tool. Further, in terms of popularity, are OPNET, GloMoSim, QualNet, and OMNeT ++. Figures 9–12 present analysis results.

5. Conclusions

In this article the authors provide a survey of the most popular network simulators: NS-2, NS-3, OMNET++, OPNET, GloMoSim, QualNet and J-Sim. The main properties of these tools are presented followed by a simple comparison. The authors also include some background information on the popularity of particular simulation tools in the form of a survey based on available sources of articles from a number of leading publishers (IEEE, Springer, Wiley and Elsevier). The survey results are also presented in the article.

Based on the conducted investigations it can be concluded that for academic researchers the best choice will be NS-3. It provides suitable libraries to address the particular applications needs. Another good choice is OMNET++, since it is also free for academic use, its users community is quite large, it is popular and one can find many additional modules or libraries for specific needs. In authors' opinion the latter choice is better for researchers that do not want to put too much effort into learning the application as it is more intuitive and, thanks to the well-designed GUI, easier to use. In terms of popularity, NS-2 appears, however, to be the best choice. Since the software is no longer being developed, the authors believe that its replacement – NS-3 – will be soon as popular as NS-2. OPNET Modeler and QualNet are also very good choices but since they are commercial applications they will not be as easily accessible to every researcher. Another good choice is GloMoSim, especially when one considers large scale networks, though, because of the lack of support and documentation, this simulator is still not as popular as those discussed above.

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Piotr Owczarek received the M.Sc. degree in Telecommunications from Poznan University of Technology, Poland, in 1999. Since 1999 he has been working as telecommunication and computer networks engineer. Currently out he carries on scientific research related to the wireless mesh network, in particular focusing on metrics and routing protocols. He is the author and co-author of several publications in this field.

E-mail: piotr.owczarek@et.put.poznan.pl
Chair of Communications and Computer Networks
Faculty of Electronics and Telecommunications
Poznan University of Technology
Polanka st 3
61-131 Poznan, Poland

Piotr Zwierzykowski received the M.Sc. and Ph.D. degrees in Telecommunications from Poznan University of Technology, Poland, in 1995 and 2002, respectively. Since 1995 he has been working at the Faculty of Electronics and Telecommunications, Poznan University of Technology. He is currently Assistant Professor at the Chair of Communications and Computer Networks. He is the author, or co-author, of over 200 papers and three books. Dr Piotr Zwierzykowski is engaged in research and teaching in the area of computer networks, multicast routing algorithms and protocols, as well as performance analysis of multiservice switching systems. Recently, the main area of his research is modeling of multiservice cellular networks.

E-mail: piotr.zwierzykowski@put.poznan.pl
Chair of Communications and Computer Networks
Faculty of Electronics and Telecommunications
Poznan University of Technology
Polanka st 3
61-131 Poznan, Poland