Simulation of WiFi Mesh Networks with Mobile Nodes

Sebastian Keller, Jonas Andre*, Florian Wiedner*
*Chair of Network Architectures and Services, Department of Informatics
Technical University of Munich, Germany
Email: sebastian2.keller@tum.de, andre@net.in.tum.de, wiedner@net.in.tum.de

***Abstract*—Investigation of WiFi networks can be performed with real testbeds or with the help of simulation software. Real testbeds are expensive and it is difficult to obtain consistent and reproducible test results. The results of simulated tests are only comparable to the real world to some extend. The advantages of simulators are lower costs and reproducibility. Simulators are particularly suitable for investigating WiFi meshes with mobile nodes, as these are difficult to implement with real testbeds.**

There are different software solutions for network visualization available. This paper describes two network simulators, *ns-3* and *OMNET++*, which are compared in terms of their capabilities to simulate WiFi mesh networks with mobile nodes. The comparison shows that *ns-3* is better when considering performance and customization, while *OMNET++* offers more features related to mesh networks with mobile nodes, e.g. extensive visualizations. Still, both provide no implementation for the latest WiFi standards.

***Index Terms*—Wifi-Networks, *ns-3*, *OMNET++*, Simulations, Wireless Mesh Network**

1. Introduction

Wireless communication is a key-technology for next generation devices of any kind. Increasing bandwidth and range of WiFi allows more and more applications to switch from wired connections to wireless ones. New medical applications use WiFi for in-body sensors [1], autonomous driving requires real-time communication between multiple road users, and wireless communication enables new features for drone swarms [2].

Simulation of networks is an attempt to imitate real properties of digital communications. They are used to speed up the development process of new WiFi features as well as to determine anomalies earlier. Simulation of wired networks is less complex, e.g. influence of the environment is less dominant and the complexity of the hardware is less. WiFi networks suffer of interference, connection losses, and retransmissions. Thus, simulation of WiFi networks is more difficult than simulation of wired networks. The data collected from a simulated wireless network can only be compared to real-world network in some extend.

Another approach to investigate WiFi networks are real testbeds. These testbeds are rather expensive, the environment needs to be screened from the surrounding environment to avoid inferences of the surrounding. Thus, the results are less reproduceable than results from simulations.

When it comes to the simulation of dynamic mesh networks, additional problems arise [2]:

1) Link-quality is not constant over time due to the limited range and moving links.
2) Links can break because nodes might move out of range. The reachable neighbours of each node change over time.
3) Routing may change, e.g. because a link loses the original communication partner, but another link is in range, which can be used for communication.

Figure 1 shows an example of a flying Ad-Hoc network which illustrates the stated problems. The WiFi coverage of each drone is illustrated by the red circles. While the drones are flying their reachable neighbours change. It must be assured, that at least one drone can connect with the gateway drone, which connects the whole swarm with the internet using a cellular connection. This illustrates how an area without cellular coverage can be covered with a WiFi network in case of an emergency.

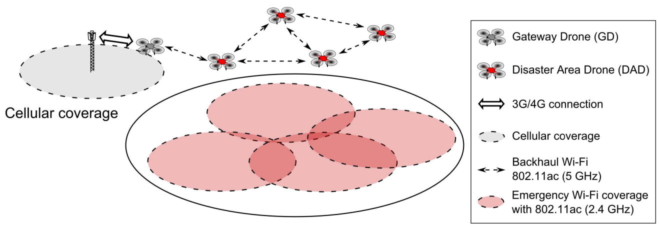

Figure 1: Flying Ad-Hoc network example [2].

The development of new wireless communication standards causes rapid progress in terms of transmission rates and new features. Thus, there exist no simulation which is capable of simulating all standards. The youngest simulation software is *ns-3*. It is the successor of *ns-2* with the focus on scalability and performance. *ns-3* is open source and it has a huge community which allows fast development of new models. *OMNET++* is a commercial solution for network simulation which is free for non-commercial use. There are other simulation software with different focus, e.g. *OPNet*, *Castalia*, *Qualnet*, *Tetcos NetSim*, *OpenSim*, *MIMIC Wireless Simulator*, and the *Wireless Sensor Networks Simulation* Extension for *Matlab*.

In Chapter 2 related work on the topic of WiFi mesh virtualization is presented. The concepts behind *ns-3* and *OMNET++* are described in Chapter 3. Afterwards the benefits and drawbacks of each simulation software are compared in Chapter 4. In the last Chapter a conclusion

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is drawn containing a short summary of the benefits and drawbacks of each.

2. Related work

The limitations of *ns-3* are explained in detail in "Network Simulation and its Limitations" [3]. According to their research, wireless network simulation provides only limited credibility and scalability. Credibility can be increased by limiting the simulation results only to certain aspects of the network, performing regressions tests, reusing existing and tested code, and by comparing the simulation results with the results from a real testbed.

Scalability is another issue for real testbeds, as the testbed is going to be more costly with increasing number of nodes. Simulations have also limited scalability. This limit can be increased by parallel computing or distributed network simulation.

Other publications present ways to extend the current available models of *ns-3* with features, which are necessary to virtualize WiFi Mesh Networks. Hany Assasa et al. show a solution for beamforming in [4]. They extended the existing *ns-3* model for *IEEE 802.11ad* to support multiple antenna beamforming.

As WiFi mesh virtualization has multiple usecases, there exist several publications which focus on specific applications like flying Ad-Hoc network systems [5] or Wireless Body Area Networks (WBAN) [6]. Dmitrii Dugaev and Eduard Siemens demonstrate the use of WiFi meshes to enable communication between multiple flying drones in [5]. The key challenges of this application are the points 1, 2, and 3 stated in Chapter 1. WBANs are used to monitor body measurements like electrocardiograms (ECG) or electroencephalograms (EEG). Beom-Su Kim et. al. use *ns-3* to build a realistic WBAN simulation system [6].

The comparison of the virtualization with the real-world is necessary to validate simulation models. This has been done by Dmitrii Dugaev and Eduard Siemens in [7]. They compared experiments in *ns-3* with a real testbed. They conclude that the physical, interference, and channel models are sufficiently accurate and they state that it can be used to evaluate performance parameters of "different wireless mesh networks with various topologies" [7]. Also, the *ns-3* model for hybrid routing schemes and link establishing algorithms can be used for this purpose.

3. Concepts

As already mentioned in Chapter 1, there exist different network simulators. Several studies [8]–[12] compare different network simulators to simulate wireless networks. The following chapters will focus on *OMNET++* and *ns-3* as they both provide good performance, are actively maintained, and free for academic use.

3.1. ns-3

ns-3 is a discrete-event network simulation tool, i.e. each step in simulation time is assigned to every active event, events are triggered consecutively in discrete steps. It is published under the *GNU GPLv2* license and thus the source code is available. The core of *ns-3* is written in *C++* while the scripting interface is written in *Python*. It is developed for research and educational purposes. In comparison to its predecessor *ns-2*, *ns-3* is developed with focus on scalability and performance.

ns-3 has modular structure containing the following main features [13]:

1) **Nodes**: a communication point, e.g. router, smartphone
2) **Channels**: interconnect multiple nodes, e.g. *PointToPointChannel* or *WifiChannel*
3) **NetDevices**: represent a physical interface on a node, e.g. an Ethernet interface
4) **Packets**: packets are sent over channels using NetDevices
5) **Sockets and Applications**: user defined processes that generate packets

These components are used to define the network topology. Figure 2 shows a schematic configuration in *ns-3*, which illustrates the structure of a *ns-3* model. For simulation of WiFi networks, the channel is a *WifiChannel* and the nodes are WiFi clients with implemented applications, which can communicate with other nodes using WiFi.

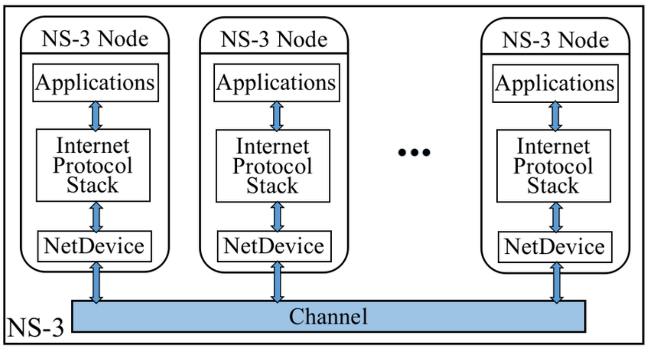

Figure 2: data flow model in *ns-3* simulation at a high-level [14].

The simulation needs to be initialized with events that will trigger the creation of further events. While the simulation is running, it is necessary that test results can be collected. *ns-3* includes a tracing subsystem which allows to measure and log data in a flexible way. The tracing subsystem can save the data collections in common data formats like *pcap*. This makes analysation with third-party software like *Wireshark* [15] possible. The simulation is terminated by either a specified simulation time, or if the list of upcoming events is empty.

ns-3 has a large community, which continuously improves existing models and adds new models. This allows to simulate the latest standards. Thus, there is a large model library available for *ns-3*.

ns-3 itself does not provide any graphical user interface. This might be an issue on the first glance, but nevertheless it has proven to be comprehensible and easy to use. There exist several third-party visualization tools like *NetAnim* to animate tracing data, *Gnuplot* for general visualizations or the already mentioned *Wireshark*.

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3.2. OMNET++

OMNET++ is a discrete-event simulator written in *C++*, just like *ns-3*. It is open source, but only free for non-commercial purposes. The commercial version of *OMNET++* is *OMNEST*. It was not originally developed as a network simulator, but as a general purpose discrete event simulator. In contrast to *ns-3*, *OMNET++* provides a graphical user interface called *OMNET++ IDE*. The *OMNET++ IDE* can be used to create NED files, which are used to define components. This includes the definition of modules, networks, and connections. *OMNET++ IDE* also includes a source editor as an alternative.

The functionality of the modules is implemented in *C++*. Each module is represented by a class which handles the initialization of a module and the overall behaviour of the module.

This network definition consisting of the NED files and C++ classes is then used to run the simulation. *OMNET++ IDE* can be used to visualize the progress of the current simulation in detail.

In contrast to *ns-3*, *OMNET++* provides many integrated visualization tools like the *TransportRouteVisualizer* to visualize traffic passing through the transport layers of multiple endpoints, the *NetworkRouteVisualizer* to visualize network layer traffic, *Ieee80211Visualizer* for *IEEE 802.11* networks and *MobilityVisualizer* to visualize the mobility of nodes. Figure 3 shows the network *Tictoc14* with 6 nodes during a TicToc simulation visualized with *OMNET++*. Packets are illustrated with a red dot, which moves between the nodes during simulation. This example counts the number of received and sent packets.

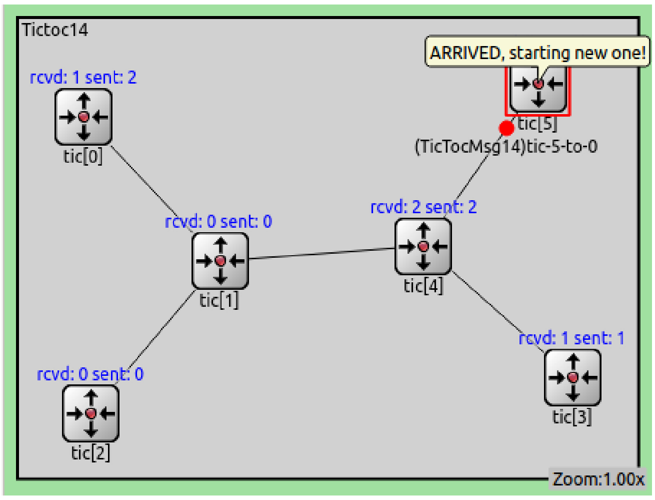

Figure 3: Example network visualization in *OMNET++* [16].

4. Comparison

The key challenges for the simulation of Wifi Mesh networks with dynamic link-quality are:

1) support for multiple antenna beamforming
2) support for Ad-Hoc routing
3) simulation of node-movement, i.e. their dynamically changing link-quality
4) simulation of packet-loss and retransmissions
5) simulation of interference

The capabilities of *ns-3* and *OMNET++* with respect to these requirements are outlined in this Chapter.

4.1. Multiple antenna beamforming

Multiple antenna beamforming is a technique that improves the signal quality with the same energy requirements. This is achieved by directional signal transmissions. The *INET Framework* of *OMNET++* supports various directional antenna, transmitters, and receivers. The *RadioVisualizer* module of *OMNET++* includes visualizations of all available antenna models. Nodes with multiple different antennas can be modeled by adding multiple wireless interfaces and assigning different antenna models to them.

As already mentioned in Chapter 2 *ns-3* has no built-in support for multiple antenna beamforming, but this functionality has been implemented in [4].

4.2. Ad-Hoc routing

The *IEEE 802.11s* standard is an extension of the *IEEE 802.11 MAC* standard which was developed to support Ad-Hoc networks with minimum hardware requirements and reduced energy consumption. The *IEEE 802.11* specification released in 2012 also includes support for mesh routing.

OMNET++ supports Ad-Hoc routing including several routing protocols *AODV*, *DSDV*, *DYMO*, and *GPSR*. Its *802.11* models includes the *Ieee80211MgmtAdhoc* management component for Ad-Hoc mode stations [16].

ns-3 does support the Ad-Hoc routing protocols *AODV*, *DSDV*, *DSR*, and *OLSR* [17]. The different protocol implementations are compared in [18]. The results showed that *OLSR* has the best performance. *ns-3* supports *802.11s* besides many other WiFi specifications, but still lacking the latest *IEEE 802.11ay* standard.

4.3. Node mobility

OMNET++ offers built-in mobility models including stationary, deterministic, trace-based, stochastic, and combined models. By default the antenna mobility model uses the same mobility model as the node itself, but it is also possible to define independent models. This allows e.g. to model a vehicle with multiple directional antennas located at different positions in the vehicle. The *MobilityVisualizer* allows to visualize the motion of mobile nodes.

ns-3 includes mobility models to define the position, velocity, and acceleration of nodes. It does not support movement along the Z dimension currently. An approach to extend the mobility model to three dimensions is presented in [19].

4.4. Packet-loss and retransmissions

The simulation of packet-losses and retransmission is necessary to identify poor connectivity, overloaded nodes, or misconfigured nodes.

Simulator	*OMNET++*	*ns-3*
Open Source	Mostly	Yes
Free for commercial use	No	Yes
Wireless support	Yes	Yes
Scalability	Medium	Good
Performance	Medium	Good
Documentation	Great	Good
Visualization	Included/Good	Third-party/Medium
Multi antenna beamforming	Yes	Possible
Ad-Hoc support	Yes	Yes
Mobility support	Yes	Yes
Packet loss/retransmissions	Yes	Yes

TABLE 1: *ns-3* and *OMNET++* Comparison

OMNET++ supports packet drops and retransmissions including a visualization for packet drops with the *PacketDropVisualizer* module.

ns-3 does support packet losses and retransmissions, too. It has an included *PacketLossCounter* class, which can be used to count the number of lost packets.

4.5. Interference

Interference in WiFi signals can have many reasons. It is mostly caused by multiple overlapping WiFi signals using the same channel. This can cause slower networking speed, higher latencies, retransmissions, interrupted connections, and the inability to connect to a WiFi network.

OMNET++ offers debugging tools to investigate interference including many different visualizations.

ns-3 does also support interference. The *InterferenceHelper* class helps to trace many information relevant to investigate the interference.

5. Conclusion and future work

A comparison of *ns-3* and *OMNET++* with respect to WiFi meshes with mobile nodes is presented in this paper. Key features a simulator needs to support are outlined. *ns-3* offers slightly better performance. One drawback is the missing visualization, but it is still possible to use third-party tools. The possibility to create common tracing files that can be viewed in third-party tools like *Wireshark* overcomes this issue only to some extent. In general *ns-3* can be considered to be a more low-level simulation than *OMNET++*.

OMNET++ has a good documentation including well documented examples. The examples in the documentation of *ns-3* are less user-friendly, but the documentation of the modules and classes is detailed. One key-feature is the included visualization tool. Table 1 lists a comparison of the most relevant features. As *OMNET++* is only free for non-commercial use, *ns-3* might be the better choice in commercial applications. Both support the simulation of wireless communication, whilst *ns-3* supports more WiFi standards in a more accurate implementation. Ad-Hoc networks can be simulated by both tools. Simulation of multi antenna beamforming, which might be necessary for Ad-Hoc networks, is only integrated in *OMNET++*. The implementation of [4] can be used to add support for multi antenna beamforming in *ns-3*, too. *ns-3* is better in terms of scalability. It provides less memory consumption and simulation time than *OMNET++*.

This paper focuses more on a raw feature comparison of the simulation tools than on the test results the simulators produce. Future work needs to investigate the comparability of simulation results with test results gained from a real testbed.

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