On The Accuracy of IEEE 802.11g Wireless LAN Simulations Using OMNeT++

Michael Bredel
Leibniz Universität
Appelstr. 9A
Hannover, Germany
michael.bredel@ikt.uni-hannover.de

Martin Bergner
TU Darmstadt
Merckstrasse 25
Darmstadt, Germany
martin.bergner@online.de

ABSTRACT

In recent years wireless network research has been mostly based on simulations. Hence, it is absolutely necessary to have correct, reliable, and trustworthy simulators. Nevertheless, while most of the authors of simulation tools provide an extensive verification of their model implementations, an accurate validation of the models is often missing and left to the research community. In this paper we present results of an extensive measurement study of wireless networks conducted in a highly controlled, almost error free environment which are applied to validate the IEEE 802.11g model of OMNeT++. To this end, we used metrics like throughput, delay and packet inter-transmission to compare the measurement results to identical simulations. We show that the simulation results match the measurements well in most cases and point out the main differences. Thus, we shed some light on the accuracy of OMNeT++.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Miscellaneous; I.6.7 [**Simulation and Modeling**]: Simulation Support Systems—*complexity measures, performance measures*

General Terms

Simulation, Measurements, Validation

Keywords

IEEE 802.11, simulation, OMNeT++, measurements

1. INTRODUCTION

Throughout the last years, simulations have been widely used to develop and investigate the behaviour of wired and wireless networks like mobile ad hoc networks, or wireless sensor networks, e.g., in [17, 15] and references therein. Due to simple setup procedures, a global view to all network events, and reproducible results simulators like NS-2 [5], OpNet [7] or OMNeT++ [6] are popular within the research community. Simulation results often lack of accuracy caused by assumptions and simplifications introduced by simulation models to handle real world complexity. To achieve reliable and trustworthy results it is absolutely crucial to have valid and verified simulation models. This can be done e.g., by comparing simulation results with real world measurements pointing out the interesting similarities and differences [19, 23]. Nevertheless, validation and verification especially of wireless network models are hard to achieve since this comparison is quite complex and often cumbersome [20, 15, 18]. But, beside inaccurate simulation results, measurement data has to be treated carefully as well. Especially in wireless networks, measurements might be defected by additional, uncontrollable noise. These aspects make the comparison of the results and simulation verification and validation an interesting and challenging task.

In this paper we present results from an extensive measurement study of IEEE 802.11g networks and compare them to OMNeT++ simulations in order to validate the accuracy of the simulator's 802.11 wireless protocol implementations. We focus on the behaviour of 802.11's distributed coordination function (DCF) rather than aspects of, e.g. the physical layer. Therefore, we compare the results of both domains with respect to packet size dependent throughput, long term fairness and packet inter-transmission. We note that all measurements have been conducted using a wireless testbed in a shielded, reflection free room. Furthermore, we perform similar experiments using OMNeT++.

The remainder of this paper is organized as follows. In Sect. 2 we review related work on simulation validation. In Sect. 3 we describe our baseline setup and compare our measurement results to the OMNeT++ simulations. Sect. 4 provides brief conclusions and an outlook to future work.

2. RELATED WORK

This section surveys background and work related to verification of various network simulators with a focus on wireless networks.

In [24] the authors compare OpNet [7] and NS-2 [5] simulation outputs to measurement results of various scenarios gathered in a wired real world testbed using tcpdump. They investigate throughput of CBR and FTP over TCP flows and found simulators to be very sound in case of CBR flows but less accurate in case of FTP sessions, at least while using default setups. The authors state simulators to be inaccurate in case of packet routing. They point out the complex-

OMNeT++ 2009, Rome, Italy.

ity of real scheduling implementations to be responsible for these inaccuracies, as they are affected by various parameters which can not be completely mapped to simulations.

In [25] the authors present an experimental validation of NS-2 by using simulation, emulation and a real world testbed. They use a wireless model implementation provided by the Monarch Project [4] and compare the simulation results like packet delivery ratios and packet latency to emulated as well as real 802.11 wireless networks. The authors focus on static multi hop ad hoc networks, hence, assuming the implementation of the wireless model to be valid.

Regarding OMNeT++, similar work was presented in [17] to validate its accuracy in the field of wireless sensor networks (WSN). The authors perform simple and clear experiments to observe metrics like packets sent and received by the application layer, corrupted packets or duplicates. Hence, they focus on the behaviour of WSN rather then issues related to medium access control. Furthermore, in [22] the authors introduce probabilistic radio propagation models into OMNeT++ and perform a cross validation check of the physical layer model with NS-2.

Despite the efforts to implement new simulation models, an investigation of 802.11 DCF behaviour that validates OMNeT++'s accuracy regarding medium access procedures remains an open issue.

3. EXPERIMENTAL VALIDATION

To validate the simulation results we conduct identical experiments in a real world testbed as well as in the OMNeT++ simulator. We investigate throughput, long term fairness, and packet inter-transmissions. That allows us to evaluate the medium access control mechanism of the 802.11 standard [3]. The real world measurements took place in a shielded, anechoic room providing a highly controllable environment. Hence, we assume that the physical medium is free of interference from external sources. Furthermore, as the distance between the stations is low we assume negligible fading.

As shown in Fig. 1 the testbed comprises of four wireless stations (S1 to S4) that serve as traffic sources. The stations are connected to an access point (AP) using IEEE 802.11g with 54 Mbps[1]. The access point is connected over fast Ethernet at 100 Mbps to a station (R) that acts as a receiver. The distance between the wireless stations and the access point was between 0.5 m and 1.5 m. We switched of RTS/CTS, automatic rate adaption as well as packet fragmentation. We used the DCF for medium access. In parallel to the wireless test network, all nodes are connected to a separated switched Ethernet, which is used as a control network. Traffic generation in the testbed was done using D-ITG [1] and rude/crude [8]. Furthermore, we used SSH-Launcher [12] scripts to automate our experiments.

To setup identical topologies in the simulation domain, we used OMNeT++ version 3.4b2 with the INET framework version 2006.10.20 and the IEEE 802.11g extension from Cocorada [16].

[1]We used Lenovo ThinkPad R61i notebooks with 2.0 GHz, 2 GB RAM running Ubuntu Linux 8.04 with kernel v.2.6.24. We employed the internal Intel PRO/Wireless 4965 AG IEEE 802.11g WLAN adapters. The access point is a Buffalo Wireless-G 125 series running DD-WRT [2] version 24.

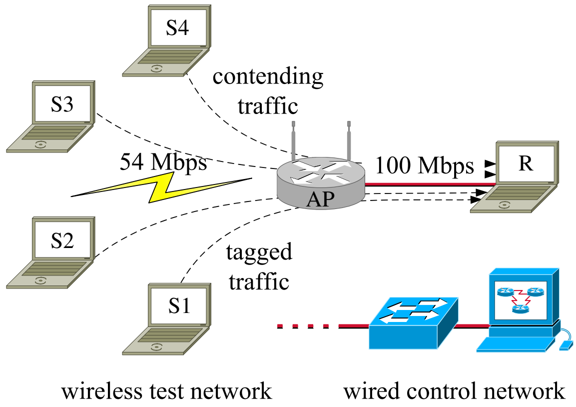


Figure 1: Wireless testbed setup

3.1 Protocol Overhead

In IEEE 802.11 it is well known that protocol overhead has a tremendous impact on the achievable throughout. In general the throughput can be determined as $C = l/g$ where l is the packet size and g is the gap, i.e. the time between the beginning of two subsequent packets transmitted at the maximum rate. In wireless networks the gap g consists of additive parameters[2] [3] including inter frame spacings, the expected backoff time, transmission times of the data packet including preamble and header, the acknowledgement, as well as propagation delays and possible retransmissions which are neglected here. This leads to a very simple analytical model for the achivable throughput in IEEE 802.11. A more complex model can be found, e.g. in [11].

In order to evaluate the protocol overhead of the simulation model that refers to correct timing settings in the MAC layer, we perform experiments that measure the achievable throughput for different packet sizes. In Fig. 2 the simulation results are compared to measurements and the simple analytical model presented above. We do not present confidence intervals as they were negligible at a confidence level of 0.95. As expected, the figure clearly depicts a strong packet size dependency of the throughput. The simulation results are quite close to the real world measurements while the simple model differs from both of them. This might be due to retransmissions that are totaly neglected in the analytical model. Nevertheless, the results clearly indicate a good performance of the simulation, hence correctness regarding the DCF timing parameters.

3.2 Long Term Fairness

The DCF tries to achieve per-station fairness with respect to the number of packts. Thus, on the assumption of equally distributed packet, sizes long-term fairness ensures a certain average throughput for each station [13].

Fig. 3 presents the throughput of several contending flows at an IEEE 802.11g link for both simulation and testbed results. For each experiment, the flows have a constant bit rate and a constant packet size of 1500 Bytes. We measure an average throughput over 60s. In Fig. 3(a) one station sends its data at 28 Mbps while the other node increases its rate from 0 to 24 Mbps in steps of 1 Mbps per experiment.

[2]We set $t_{difs} = 28\mu s$, $t_{sifs} = 16\mu s$, $t_{backoff} = 67.5\mu s$, $t_{data} = 26\mu s + (l/54)\mu s$, $t_{ack} = 30\mu s$

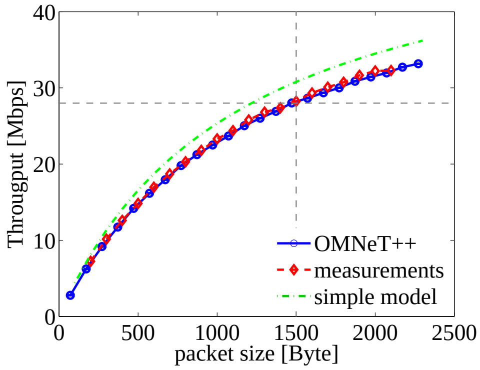


Figure 2: Packet size dependency of throughput in 802.11. OMNeT++ matches the measurement data quite well, while the simple analytical model yields a higher throughput.

Likewise, Fig. 3(b) shows the throughput of four contending flows, where one flow increases its rate while the others send their data at 2, 9, and 28 Mbps respectively. Again, due to their negligible size, we do not show any confidence intervals.

We note that in both scenarios the simulation results matches our measurements almost perfectly. This indicates a correct implementation of the medium access procedures that also works well in case of several contending stations.

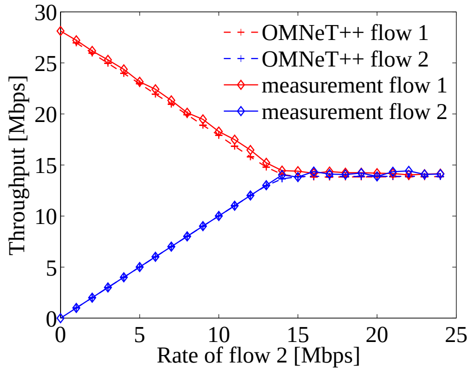
3.3 Packet Intertransmissions

[9, 10] introduced the metric of packet inter-transmissions, i.e. the number of packets k that are transmitted by a second station while a first stations transmitts two packets, for fairness. This original metric is extended by [14] to M contending stations where one tagged stations transmitts l successive packets. The resulting probability mass function (pmf) of the conditional distribution $P[K = k|l]$ is proposed as a general metric for fairness achieved by the DCF. In the following, we use the packet inter-transmissions as a performance metric in order to evaluate and compare the packet scheduling of the testbed and OMNeT++.

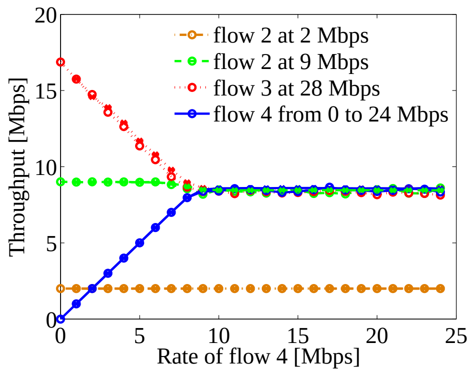
We perform the experiments with up to four contending stations lasting for a sufficient amount of time to capture about 150.000 packets for statistical analysis. Each station transmits a CBR flow at a rate of 28 Mbps with 1500 Bytes per packet. Note that this sending rate is above the fair share a single station can obtain in this scenario [13]. Due to the long term fairness ambition of the DCF [21, 9] all stations in the experiments transmit their data with average rates of 14, 9.3, and 7 Mbps with respect to the number of contenting flows.

To compare the testbed measurements to OMNeT++ simulations, Fig. 4 shows the pmf of the inter-transmissions k for different l. We find that the simulation results match the measurement data very well. Furthermore, for longer observation periods, i.e., for bigger values of l, the matching seems to be improved. We present quantile-quantile (q-q) plots that can be used for diagnosing deviations between probability distributions to explore the differences between the measurement data and the simulation results and to detail the goodness of fit. Fig. 5(a) presents the quantiles of the measurement data over the simulation data indicating that almost 0.99 of the samples coincide. Nevertheless, we observe deviations at the tail end of the distributions, which suggest different behaviour of the simulator compared to the real world testbed in some rare cases. To this end, the simulator might be unsuitable to perform rare event simulations like in case of fairness or delay investigations as it can lead to wrong results. Fig. 7(a) and Fig. 5(b) show the q-q plots for $l = 40$ and $l = 160$ respectively and support the findings from above. Almost 0.99 of the measurement and simulation samples coincide and improve for larger l. Nevertheless, even for longer observing times there is a deviation at the tail ends.

Fig. 7 compares the simulation results with two, three, and four contending stations to the corresponding measurement data. For three, respectively four stations and an observation interval of $l = 40$ packets, we discover that the distribution of inter-transmissions achieved by the simulation differs from the measurements. While 0.99 of the samples match in case of two contenting flows (see Fig. 7(a)) we note that this effect is reduced in the case of three contending stations. This can be seen in Fig. 7(b). As presented in Fig. 7(c), this even gets worse for an increasing number of stations that contend for the medium.



(a) two contending flows



(b) four conteding flows

Figure 3: Fair share througput of contending flows for $M = 2$ and $M = 4$ at different rates. On the average of 60 s the measurements and the simulation results match almost perfectly.

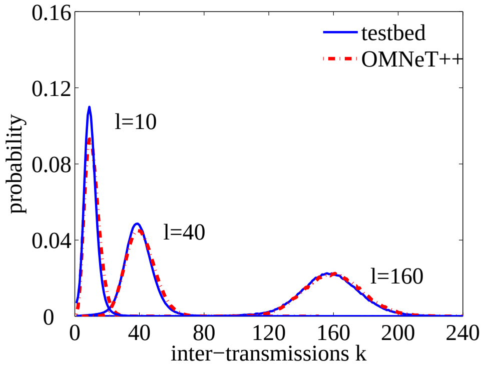
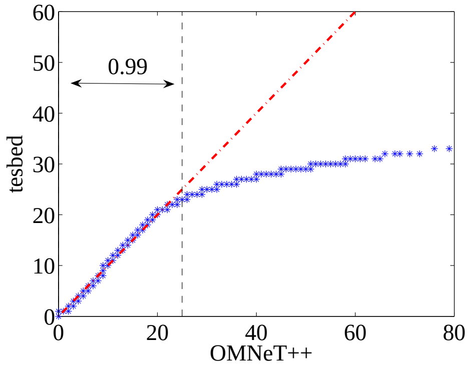
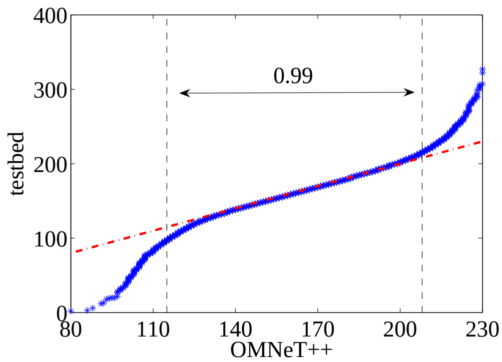


Figure 4: The pmf of packet inter-transmissions for $M = 2$ stations. The data matches quite well for short packet streams e.g, $l = 10$ and is even enhanced for larger stream length e.g, $l = 160$.



(a) q-q plot for $l = 10$, $M = 2$



(b) q-q plot for $l = 160$, $M = 2$

Figure 5: The q-q plots that correspond to the pmf presented in Fig. 4 for $l = 10$ and $l = 160$ and for $M = 2$. They differ at the tails but matches well for a 0.99 interval indicating a good simulation performance in most cases but also some differences in rare cases.

4. CONCLUSIONS

We performed a circumstantial measurement study to validate simulation results obtained by OMNeT++. We focused on the implemented DCF behaviour and compared testbed measurements conducted in a highly controllable environment to simulation results. We used metrics such as packet size depended throughput, fair share throughput in case of several contending stations, and distribution of inter-transmitted packets for comparison. Based on our experiments, we found that OMNeT++ performs quite well in case of long observation times and on average behaviour. Nevertheless, we observed a difference in case of the inter-transmission distribution pointing to a difference in the packet scheduling. This possibly limits the application of OMNeT++ e.g., in case of rare network events and should be considered and addressed in future work.

5. ACKNOWLEDGMENTS

We would like to thank M. Fidler for all fruitful discussions and inputs to our work. Furthermore, we thank M. Hollick, R. Steinmetz, and R. Jakoby for providing the equipment and facilities that made this research possible. This work has been funded by an Emmy Noether grant of the German Research Foundation.

6. REFERENCES

[1] D-ITG: Internet Traffic Generator. `www.grid.unina.it/software/ITG`.

[2] dd-wrt: Linux wireless router. `www.dd-wrt.com`.

[3] IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Spedifications.

[4] Monarch project. `www.monarch.cs.rice.edu/cme-ns.html`.

[5] NS-2: Network simulator. `www.isi.edu/nsnam/ns`.

[6] OmNet++: Network simulator. `www.omnetpp.org`.

[7] OpNet: Network simulator. `www.opnet.org`.

[8] Rude/Crude: UDP Data Emitter/Collector. `rude.sourceforge.net`.

[9] G. Berger-Sabbatel, A. Duda, O. Gaudoin, M. Heusse, and F. Rousseau. Fairness and its impact on delay in 802.11 networks. In *Proc. of IEEE GLOBECOM*, pages 2967–2973, Nov. 2004.

[10] G. Berger-Sabbatel, A. Duda, M. Heusse, and F. Rousseau. Short-term fairness of 802.11 networks with several hosts. In *Proc. of IFIP MWCN*, pages 263–274, Oct. 2004.

[11] G. Bianchi. Performance analysis of the IEEE 802.11 distributed coordination function. *IEEE J. Select. Areas Commun.*, 18(3):535–547, Mar. 2000.

[12] Z. Bozakov and M. Bredel. SSHLauncher.KOM - A tool for experiment automation in distributed environments. Technical report, TU-Darmstadt, Merckstr. 25, 64283 Darmstadt, Jul 2008.

[13] M. Bredel and M. Fidler. A measurement study of bandwidth estimation in IEEE 802.11g wireless LANs using the DCF. In *Proc. of IFIP Networking*, pages 314–325, May 2008.

[14] M. Bredel and M. Fidler. Understanding fairness and its impact on quality of service in IEEE 802.11. In

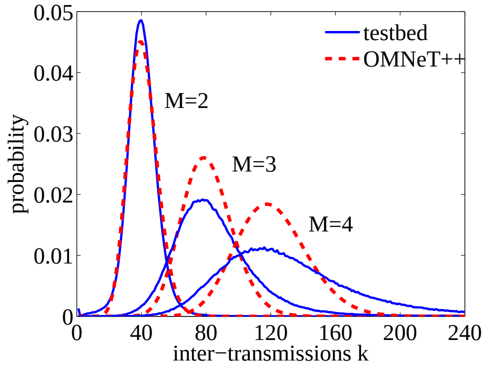


Figure 6: pmf of inter-trans-missions for $l = 40$.

Proc. of InfoCom, Apr. 2009.

[15] D. Cavin, Y. Sasson, and A. Schiper. On the accuracy of MANET simulators. In *Proc. of ACM POMC*, pages 38–43, Oct. 2002.

[16] S. Cocorada. An IEEE 802.11g simulation model with extended debug capabilities. In *Proc. of Simutools*, pages 1–3, Mar. 2008.

[17] U. M. Colesanti, C. Crociani, and A. Vitaletti. On the accuracy of OmNet++ in the wireless sensornetworks domain: simulation vs. testbed. In *Proc. of ACM PE-WASUN*, pages 25–31, Oct. 2007.

[18] F. Haq and T.Kunz. Simulation vs. emulation: Evaluating mobile ad hoc network routing protocols. In *Proc. of IEEE IWWAN*, May 2005.

[19] R. Jain. *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulations, and Medeling.* Wiley-Intersience, 1991.

[20] D. B. Johnson. Validation of wireless and mobile network models and simulation. In *Proc. of the DARPA/NIST Network Simulation Validation Workshop*, May 1999.

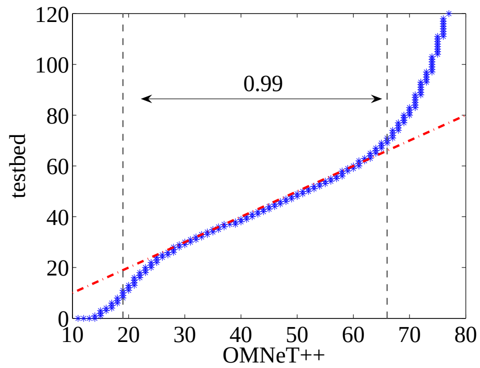
[21] C. E. Koksal, H. Kassab, and H. Balakrishnan. An analysis of short-term fairness in wireless media access protocols. In *Proc. of ACM SIGMETRICS*, pages 118–119, June 2000.

[22] A. Kuntz, F. Schmidt-Eisenlohr, O. Graute, H. Hartenstein, and M. Zitterbart. Introducing probabilistic radio propagation models in omnet++ mobility framework and cross validation check with ns-2. In *Proc. of Simutools*, pages 1–7, Mar. 2008.

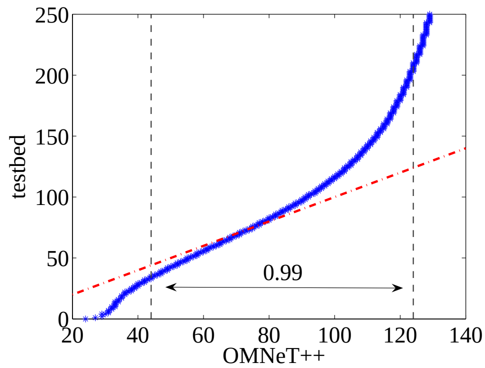
[23] A. M. Law and W. D. Kelton. *Simulation Modeling and Analysis.* McGraw-Hill, 1991.

[24] G. F. Lucio, M. Paredes-Farrera, E. F. Jammeh, and M. J. Reed. Opnet modeler and ns-2 - comparing the accuracy of network simulators for packet-level analysis using a network testbed. *WSEAS Transactions on Computers*, 2(3):700–707, July 2003.

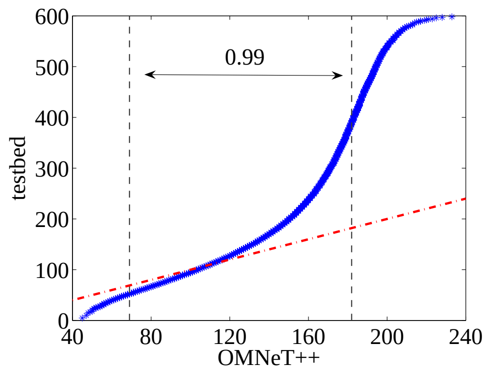
[25] A. H. S. Ivanov and G. Lukas. Experimental validation of the ns-2 wireless model using simulation, emulation, and real network. In *Proc. of WMAN*, pages 433–444, Feb. 2007.



(a) q-q plot for $l = 40$ and $M = 2$



(b) q-q plot for $l = 40$ and $M = 3$



(c) q-q plot for $l = 40$ and $M = 4$

Figure 7: The simulation performance is quite good for $M = 2$ but it decreases for more than two stations. The mean value of the inter-transmission still matches quite well. Nevertheless, the distributions show some differences. This suggests that the packet scheduling between the testbed and the simulation is different.