Introducing Probabilistic Radio Propagation Models in OMNeT++ Mobility Framework and Cross Validation Check with NS-2

A. Kuntz, F. Schmidt-Eisenlohr, O. Graute, H. Hartenstein, M. Zitterbart
Institute of Telematics, University of Karlsruhe, Germany
{akuntz|fschmidt|s_graute|hartenstein|zit}@tm.uka.de

ABSTRACT

When performing wireless network simulations, the lack of precise channel modeling in simulator frameworks becomes a serious problem. Often deterministic models are used for packet propagation, which describe real conditions insufficiently. To close this gap we extended the OMNeT++ Mobility Framework to support probabilistic propagation models. We provide an implementation for the Log-Normal-Shadowing, Nakagami, Rayleigh and Rice wave propagation models and set up a framework that allows easy integration of additional models in future.

Due to the characteristics of probabilistic radio models a fixed maximum packet propagation range encounters the problem of inaccurate simulation results as relevant events may be suppressed. On the other hand, unlimited packet propagation, which guarantees for correct simulation runs, causes unnecessary simulation overhead. In this work we present an approach to limit the event delivery to the area where the probability that the event is relevant to the simulation exceeds an adjustable threshold. In order to validate our extensions we successfully performed a detailed cross-check with the network simulator NS-2 and run a performance evaluation and comparison.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*;
I.6.7 [**Simulation and Modeling**]: Simulation Support Systems

General Terms

Design, Experimentation, Measurement, Performance

Keywords

Ad hoc networks, simulation, OMNeT++, probabilistic propagation

OMNET++ 2008, March 03, Marseille, France

DOI 10.4108/ICST.SIMUTOOLS2008.3081

1. INTRODUCTION

Network simulation frameworks are very popular in network research. They provide the possibility to gain deep and detailed insight into the behavior of protocols and architectures in a cost efficient and controllable way. Current research often depends on simulations as the concepts need to be tested before being implemented in real networking devices. Hereby, accuracy is an important requirement, as the simulation is meant to reflect the behavior in reality.

For wireless networking research, the exact modeling of the wireless channel is of particular importance. Many problems originate from unpredictable link characteristics and related phenomena. Although the deterministic unit disk graph model is known to reflect the complex characteristics of the wireless channel only insufficiently (see e. g. [3]), it is still commonly used in network simulators. Alternative approaches are rarely found in current network simulation frameworks. Main issues in real world scenarios are unidirectional and instable links with changing link quality [9], which cannot be represented by a deterministic model.

To close this gap, we introduce probabilistic propagation models into the OMNeT++ Mobility Framework simulation environment [5]. Furthermore, we propose a method to trade off between simulation accuracy and simulation speed. The accuracy is given in terms of a maximum probability, that a host is not notified about an event although the event would have been relevant with respect to the course of simulation. In a cross validation check, we compare our simulation outcome to results obtained using the NS-2 simulator [1]. This, on the one hand, enables us to validate our framework extension and the framework itself. On the other hand it allows for a performance comparison with another simulator.

The rest of this paper is organized as follows: Section 2 discusses the simulation of the wireless channel and the issues introduced by deterministic and probabilistic propagation models. Section 3 gives an overview on the current status in simulating wireless communication and the models used. Section 4 shows how a maximum propagation range is obtainable with an adjustable level of simulation error. In Section 5 we describe how the shown approach is integrated into the OMNeT++ Mobility Framework before in Section 6 simulation results and the cross validation are shown. Finally, Section 7 concludes this work.

2. WIRELESS CHANNEL SIMULATION

Generally, the wireless channel has to be seen as a highly chaotic and unpredictable system. Basically, a transmitted signal is being reflected, scattered and absorbed by any ob-

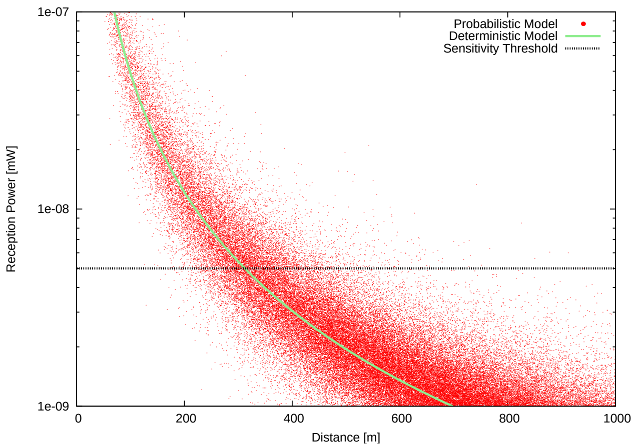

Figure 1: Exemplary development of signal power with respect to the distance between sender and receiver

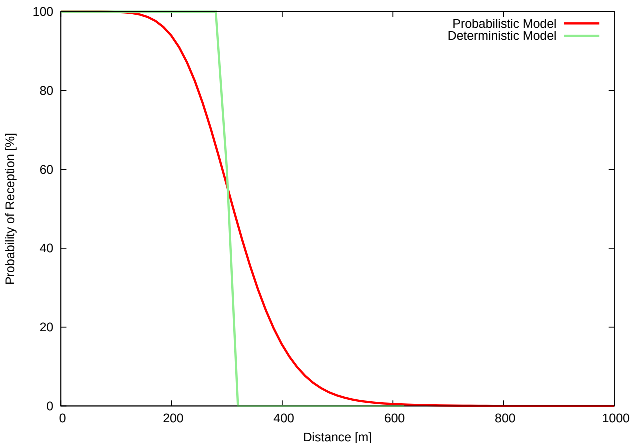

Figure 2: Exemplary development of reception probability with respect to the distance between sender and receiver

ject during its transmission. As the signal does not only take one single path it can also influence itself. Also, other transmissions and even signals sent in other frequency ranges might influence the signal.

Exemplary, Figure 1 shows the observed signal powers generated using a deterministic and a probabilistic propagation model within a network simulator. The horizontal line exemplifies the receiver's radio sensitivity threshold. Signals above this threshold may be received by the receiver, lower level signals only contribute to the respective noise level. For both models, the (average) reception power drops with the distance. In contrast to the deterministic model, the probabilistic one shows an intensive dispersion of its values.

The reception power for the *deterministic* model intersects the sensitivity threshold in a certain distance. This distance is often referred to as communication range. Nodes inside the communication range are able to receive 100% of the messages, whereas nodes outside this communication range will not be able to receive a single message.

At this distance, the probability of reception instantaneously drops from 100% to 0%, resulting in the well known and often criticized unit disc graph model. Due to the broader variance of the *probabilistic* reception power graph, it does not intersect the sensitivity threshold in a single point. The intersection rather is an interval, in which the amount of power samples above the threshold smoothly declines to zero. Analogous, the reception probability in this interval fades from 100% reception probability in the proximity of the sending node, to close 0% in further distance. Figure 2 shows the resulting reception probabilities for the given reception powers and sensitivity. This discussion illustrates the difficulty of defining a fixed communication range in presence of randomly scattered signal powers. For a fixed distance, there can only exist a certain probability of receiving a message.

Similar to the communication range problem, it is difficult to define a maximum propagation range for a specific simulation setup. This maximum propagation range is supposed to specify how far a message should be propagated over the playground. So it determines which nodes are notified about a sending event. This is the maximum distance where a message (as a simulation event) may influence the simulation run, inducing successful and unsuccessful receptions as well as contributing to the receiver's noise and interference level. If it is set too small, relevant interferences between messages may not be simulated correctly. On the other hand, propagating each message all over the playground and hence delivering it to each node, slows down the simulation. This is because the number of generated simulator events grows with the product of the number of disseminated messages and the number of notified nodes.

3. STATE OF THE ART

In current network simulators different models are used that describe the effects on the wireless channel. This can be done in different levels of detail, what clearly influences the accuracy of the results being generated by a simulation. Many simulators leave choice to select one of several given models, and to parametrize them according to the user's needs. The Network Simulator 2 (NS-2) incorporates three models by default, that are Free Space, Two Ray Ground and Log Normal Shadowing. The Nakagami model [4] is a generic and probabilistic propagation model and was proposed and implemented for NS-2 in [8]. OMNeT++ by default supports the deterministic Free Space model only. In this work we enhanced OMNeT++ with all these models.

The *Free Space* model [6], also known as Friis propagation model, calculates the average radio signal attenuation over distance d. When assuming isotropic propagation of waves this relates to a quadratic loss of signal power over distance:

$$Pr_{det}(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{1}$$

P_t denotes the transmission power, G_t and G_r the transmitters and receivers antenna gains, λ the used wavelength and L the system loss factor. Although the parameters can be adjusted the model behaves completely deterministic and neglects physical effects like reflection, scattering or fast fading. Consequently, in a scenario with a single transmitter and several receivers, the area containing successful receivers is a fixed circle. As such, this model is highly idealistic and unrealistic.

The *Two Ray Ground* model [6] takes into account an additional reflection on the ground in the pathloss calculation. By this, in further distances the quadratic pathloss is replaced by one to the power of four:

$$Pr_{TRG}(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \tag{2}$$

where h_t and h_r denote the antenna heights. Although the conceived reception powers match reality better, this model still is deterministic and has a circular-shape reception area.

Probabilistic models allow a more realistic modeling of radio wave propagation. Typically the average reception power at a specified distance is still calculated using a deterministic model, in our case Free Space. Yet, the individual reception power of each arriving frame is determined using a probability distribution with the average reception power as one of the parameters. This results in a much more diverse (and realistic) distribution of successful receptions. A clear geometric partitioning is not visible anymore, instead, receptions in near distance might fail, as well as receptions in distances further than the classic reception range are also possible. The intensity of aforementioned effects depends on parametrization and the characteristics of the probabilistic models.

A well known representative of probabilistic models is the *Rayleigh* propagation model [6]:

$$Pr_{Rayleigh}(d) \sim \text{Rayleigh}(Pr_{det}(d)) \tag{3}$$

It models non-line-of-sight communication and thus incorporates intensive variations of signal reception power, i. e., a strong influence of the environment. The reception powers are distributed following the Rayleigh distribution with the average power being the power determined by the deterministic pathloss model. The Rice distribution additionally takes into account the positive effects of a line-of-sight path with a certain scale factor k.

Log-Normal Shadowing [6], that is implemented in NS-2, uses a normal distribution with selectable variance σ to distribute reception power in the logarithmic domain. Thus, reception powers are log-normally distributed:

$$Pr_{LogNormal}(d; \sigma^2) \sim \text{LN}(Pr_{det}(d), \sigma^2) \tag{4}$$

A highly generic probabilistic model is the *Nakagami* fading model [4] where reception powers follow a gamma distribution:

$$Pr_{Nakagami}(d; m) \sim \text{Gamma}\left(m, \frac{Pr_{det}(d)}{m}\right) \tag{5}$$

The parameter m specifies the intensity of fading effects and covers a wide range of fluctuation intensity. For specific m-values it also includes existing models. Exemplary, choosing $m = 1$ reflects the Rayleigh distribution, whereas for high m-values a behavior similar to Free Space, yet probabilistic, is observable, as reception powers do not vary much. The Nakagami model is proven to reflect certain environmental conditions and the consequences on reception power well, e.g, in case of communication between vehicles on highways measurements show the applicability of the model, see [8].

4. ANALYSIS OF MAXIMUM PROPAGATION DISTANCE

Accurate physical modeling in wireless network simulations affords two major subjects: first, signal propagation, power loss and signal power variations caused by multipath-fading have to be modeled appropriately. Second, reception handling has to be modeled accurately, including the calculation of interferences and packet timing.

When regarding cumulative interferences in network simulations all relevant events have to be included in the calculation, i. e., power sources coming from packet transmissions. In order to do calculations with the highest possible precision interferences from all nodes, regardless of their distance to a node looked at, have to be taken into account. Unfortunately, this conflicts with efficient simulations where the number of receivers being informed should be small. In the following we will describe a method to determine an appropriate trade-off for setting a maximum range to inform nodes of packet transmissions

The method requires the definition of two values: the *relevance power level* p_{min} and the *level of acceptable error* ϵ. Whenever the cumulated powers at a node exceed p_{min} the corresponding events are regarded as relevant. Yet, as a first approximation we regard all packet arrivals with a power $P_r > p_{min}$ as relevant. The method now determines a maximum propagation distance d_{max} such that the ratio of relevant events not being taken into account for reception consideration is limited to ϵ.

For any distance d we calculate the expected average reception power p' using the deterministic Free Space model shown in Equation 1:

$$p' = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{C}{d^2} \tag{6}$$

and introduce the constant C:

$$C := \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 L}. \tag{7}$$

We now assume the reception powers being a random variate X following the probability density function (pdf) $f_{p'}$. Additionally we assume the cumulative density function (cdf) $F_{p'}$ corresponding to $f_{p'}$ being known and expressible. For instance, in case of Rayleigh (or Nakagami-1) distributed reception powers we obtain:

$$f_{p'}(x) = \frac{1}{p'} \exp\left(-\frac{x}{p'}\right) \tag{8}$$

$$F_{p'}(x) = 1 - \exp\left(-\frac{x}{p'}\right) \tag{9}$$

By definition, $F_{p'}(x)$ expresses the ratio of packets that have a reception power smaller than x, and respectively $1-F_{p'}(x)$ the ones with a higher reception power. By setting $x = p_{min}$ the ratios of relevant and irrelevant events for each p' can be derived. By combining Equations (6), (7) and (9) we derive $R(d)$ giving the ratio of relevant events at each distance d

$$R(d) = 1 - F_{p'}(p_{min}) = \exp\left(-\frac{p_{min} d^2}{C}\right). \tag{10}$$

The resulting behavior is shown in Figures 3 and 4 for a parameter setting according to Table 1 and a '*grid-1*' scenario as listed in Table 2. A detailed description of the scenario setup can be found in Section 6.1. Figure 3 shows the ratio of relevant events at all distances between sender and receiver. Obviously the curve shows high similarity to the gained probability of successful packet reception in case of a single sending node, e.g., shown in Figure 2. In Figure 4

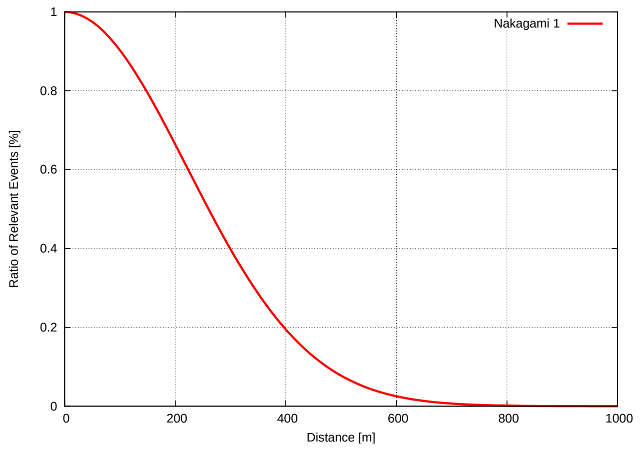

Figure 3: Probability of relevant events depending on the distance between sender and receiver

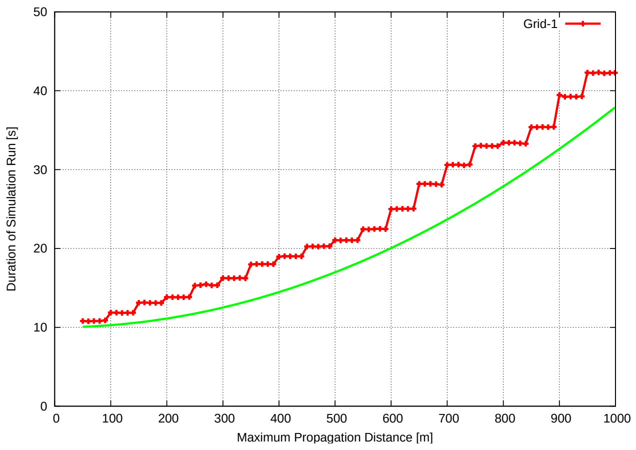

Figure 4: Simulation runtime depending on increasing maximum transmission range

measurements of simulation runtime are shown, depending on the chosen maximum propagation distance. The runtimes follow a quadratic behavior due to the fact that the number of nodes within a circle grows quadratically with the radius, as shown in the lower plot in Figure 4. The stepwise increase of measured runtimes occurs due to the positioning of nodes in a grid with a distance of 50 m. In consequence, limiting the maximum propagation distance is an adequate way to improve simulation runtime.

The presented results show the effectivity of limiting the maximum propagation range d_{max}. For a certain level of acceptable error ϵ it can now be derived by inverting Equation (10):

$$d_{max} = \sqrt{-\frac{\ln(\epsilon)C}{p_{min}}}. \tag{11}$$

Finally the selection of p_{min} and ϵ should be discussed. We suggest to set p_{min} to the sensitivity threshold of the wireless interface as reception powers above this level definitely have an influence on reception behavior. In our simulations for ϵ a value of 2% turned out to be sufficient not to change simulation results in its basic behavior. Nevertheless selection of these values has to be investigated deeper in future research. Also, the derivation of according expressions for other propagation modules and for other parameters is left open.

5. IMPLEMENTATION

Referring to the OMNeT++ homepage [5], the Mobility Framework is the ”preferred platform for mobile and ad-hoc simulations”. For modeling signal strength, the Mobility Framework only offers the deterministic free space propagation model. Yet, it does not support any probabilistic wave propagation model.

Our extension is designed to maintain the full and unchanged functionality of the original Mobility Framework implementation. A switch selects the desired propagation models, which can be specified in the configuration file. Available models are the newly introduced Free Space, Nakagami, Rayleigh and Rice propagation model, as well as the Mobility Framework's original Free Space implementation. The difference between the two Free Space implementations is, that the new Free Space model accounts for sender's and receiver's antenna gains (G_t and G_r) and for the system loss factor (L), which were omitted in the original implementation.

In order to provide a clear and extensible design, all propagation model implementations derive from a common super class, which enforces a consistent interface. Thus, the super class declares two methods to access the two model dependent functionalities: (1) Calculation of the reception power for an air frame, given the distance between sender and receiver. (2) Calculation of the maximum propagation distance. As the model implementations are stateless, it is possible to apply the singleton design pattern. This asserts that there is only one single propagation model instance, which serves for the entire simulation. This prevents from accidentally using different models for different hosts as a result of corrupted configuration files.

The Mobility Framework has two key modules which need to access the propagation model: These are the Channel Control and the SnrEval module. The Channel Control module is responsible for establishing and releasing connections between the hosts. Thereby it determines which hosts get informed about a message, depending on the maximum propagation distance. As discussed in Section 4, this parameter is heavily model dependent and therefore provided by the current propagation model instance. Alternatively, the maximum propagation distance can be set to a fixed distance if the appropriate value is specified in the configuration file. The SnrEval module is located inside the network interface card module of each host. For each incoming frame it determines the respective reception power and updates the signal to interference and noise ratio (SNIR). Thus it collects the signal strength of incoming frames and assesses the hosts' view on the local SNIR conditions.

6. SIMULATION RESULTS

To perform the cross validation check and to evaluate our contribution, we set up the same simulation scenarios in OMNeT++ Mobility Framework and in NS-2.

Average sending interval	1 s ± 0.5 s
Transmission power	5 mW
Sensitivity	-83 dBm
Channel bit rate	11 Mbit/s
Playground size	$2000 \times 2000\, m^2$

Table 1: General parametrization

Scenario	*chain-1/40*	*grid-1/100*	*random-1/100*
Topology	chain	grid	random
No. senders	1/40	1/100	1/100
Sim. duration	1000 s/25 s	1000 s/10 s	1000 s/10 s
No. hosts	40	1600	1600
Node distance	50 m	50 m	random
No. seeds	10	10	10

Table 2: Scenario dependent parametrization. The trailing number in the scenario name corresponds to the number of senders.

6.1 General Simulation Setup

The nodes are placed on a $2000 \times 2000\, m^2$ playground with a spacing of 50 m. To avoid border phenomenons, torus wrapping is activated. The wireless channel bit rate is set to 11 Mbit/s. All nodes are configured having a transmission power of 5 mW and a sensitivity value of -83 dBm. Senders periodically disseminate a message of 1576 bytes each second. To avoid systematic collisions, the initial sending time is chosen randomly between simulation start and the first simulation second. Additionally the period length is randomly varying ±0.5 s. Table 1 summarizes the parameters.

The simulations are grouped in three network topologies, named *chain*, *grid* and *random*. In the chain topology, there are 40 nodes placed every 50 m in a straight line. The grid topology places 1600 nodes with an inter node spacing of 50 m in a regular grid. So there are 40 lines containing 40 nodes each, filling the whole playground uniformly. In the random topology the total number of nodes is the same as in the grid topology, but the node's position is drawn from a uniform distribution.

We simulated each topology with a single sender and with multiple sending nodes, namely 100 for the grid and random topology and 40 in the chain topology. The trailing number in the scenario name defines the number of senders, whereas all other nodes receive only. The simulation time limit is adjusted to get an average of 1000 sending events per run. Each scenario was executed for 10 different seeds. The scenario dependent parametrization is given in Table 2.

We evaluate each scenario using the Free Space propagation model and the Nakagami propagation model, the latter one with the m-parameter set to 1, 3 and 5. We chose Free Space as it is a simple deterministic model and basis for many other models. As representative for probabilistic models, we decided to present the Nakagami model, because it is a very generic model (see also Section 3). The maximum propagation range for the simulations using the Free Space model could be obtained by inverting the Free Space formula. To observe also interference effects, we reduced the sensitivity threshold for this calculation by 6 dBm (which results in a nearly 4 times increased sensitivity). The resulting maximum propagation range is 623.76 m. This calculation is not applicable to the Nakagami model. As the maximum propagation range is until now only derived for m = 1, we set it to half the torus diameter, the maximum value on a torus.

6.2 Cross Validation Check

For the cross validation check, the two simulation environments needed to be made comparable. This includes the ability to provide equivalent simulation setup files, as well as being able to match the simulators' output files statistically and semantically. To assure close functional equivalence, we had to add functionalities and bug fixes to both simulation frameworks. OMNeT++ Mobility Framework initially did not support wireless propagation delay. We found a flaw in the torus implementation which caused missing node notifications in cases where the propagation range calculated by the deterministic free space propagation model is not a factor of the playground size. Analyzing the drop reasons, we found that the Mobility Framework allows its network interface cards sending and receiving at the same time, which is not realistic in wireless scenarios. The detailed analysis of packet drop numbers and their respective drop reasons turned out to be a very sensitive indicator for the semantics of a simulation run. We patched these issues and are looking forward to contributing the patches into the respective development branches. The applied NS-2 fixes are described in detail in [2] [7].

In all mentioned scenarios, we evaluated the reception probabilities with respect to the distance between sending and receiving host. Exemplary, we present the results for the grid-1, grid-100, random-1 and random-100 scenarios in Figures 5 – 8. The four graphs in each figure show the deterministic free space propagation model and the probabilistic Nakagami propagation model, with m-parameter set to 1, 3 and 5 respectively. Results gained with OMNeT++ Mobility Framework are shown as lines, whereas NS-2 results are given as dots.

The graphs for the Free Space propagation model show the typical deterministic unit disc graph behavior. In the scenarios with multiple senders, however the reception rates slightly drop in farther distances. This is due to packet collisions and interferences. The Nakagami plots show the expected smooth decrease of reception probability, the intense depending on the m-parameter. It can easily be seen that the results in all simulated scenarios perfectly match on top of each other. Hence we conclude that the simulators produce interchangeable results.

6.3 Performance Evaluation

The usability of advanced propagation models in a simulation environment heavily depends on the model's influence on the overall simulation performance. In this section, we survey the impact of probabilistic propagation models on the overall simulation performance, to point out the usability of complex physical layer models even in large scenarios with much communication. We compare simulation speed and memory usage of similar simulations using the original Mobility Framework, our extension with probabilistic models and NS-2. The simulations are run on a Dual Intel(R) Xeon(R) CPU 5140 @ 2.33G Hz with 32 GB RAM, hyper-threading enabled.

In terms of simulation speed, we show the achievable number of simulated seconds that can be performed in one real second, so higher values reflect better performances. We

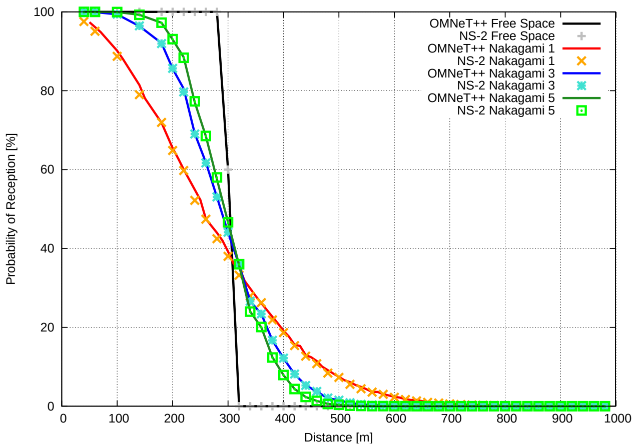

Figure 5: Probability of reception in scenario with grid topology and 1 sender

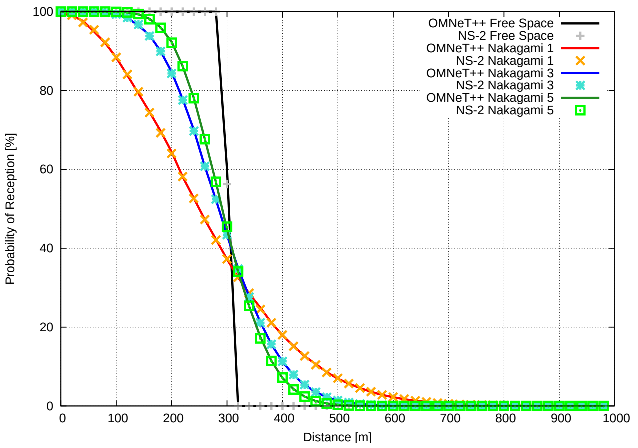

Figure 7: Probability of reception in scenario with random topology and 1 sender

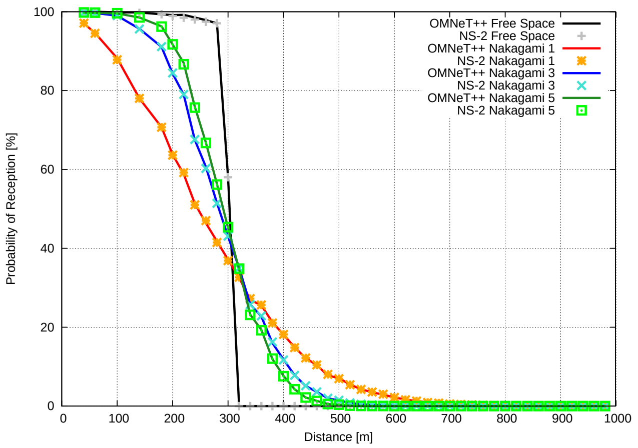

Figure 6: Probability of reception in scenario with grid topology and 100 senders

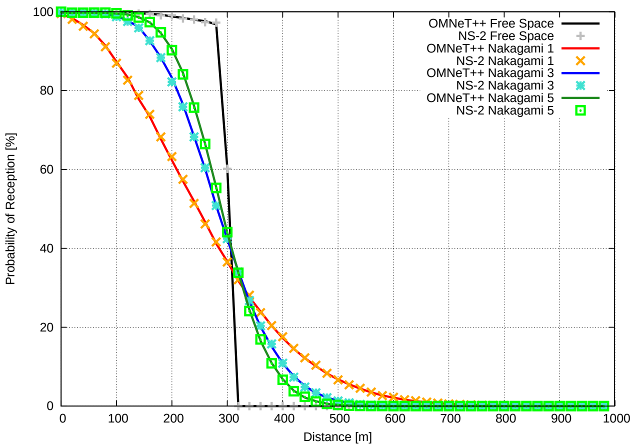

Figure 8: Probability of reception in scenario with random topology and 100 senders

first investigate on the grid-1 scenario, see Figure 9. Deterministic simulations run faster than the probabilistic ones, but it has to be taken into account, that the maximum propagation range has to be chosen higher for the latter models. Consequently, calculations at more possible receivers have to be performed.

In Figure 10 we show the same measurement for the multiple sender scenario. The general tendency is similar but keep in mind that performance heavily decreases with increasing number of transmitting nodes. Both Figures show a better performance of the OMNeT++ simulation framework.

Figure 11 shows the memory usage in MB for the grid scenarios with one and 100 sending nodes. NS-2 needs approximately constant memory for all scenarios, independently from the applied propagation model. The memory utilization of OMNeT++ is generally smaller, but slightly increases when switching from deterministic to probabilistic models. The extension of OMNeT++ did not have any significant influence on the memory usage.

7. CONCLUSION

In this paper we presented the extension of the OMNeT++ Mobility Framework with probabilistic radio propagation models. We introduced an easy to use and minimally invasive framework to support such models. Further on we presented a method to trade off between accuracy and speed of simulations. Accuracy is specified in terms of the probability that a host is not notified about an event although the event would have been relevant. Our approach is cross checked with NS-2 in order to gain validation on correctness of simulations. The closing performance measurements show that the improved simulator does not suffer from the extensions implemented.

The extended OMNeT++ Mobility Framework now allows researchers to perform more realistic wireless network simulations that fulfill accuracy and performance limits. The source code is freely available within the Sensor Network Extensions for the OMNeT++ Mobility Framework and can be downloaded under `http://www.tm.uka.de/sne4omf`.

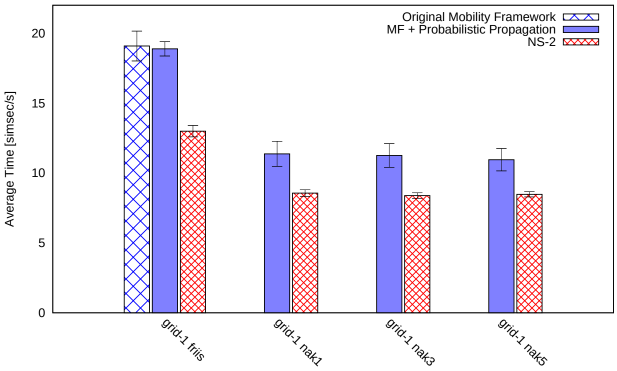

Figure 9: Simulation speed in terms of simulated seconds per real second for the grid topology and 1 sender

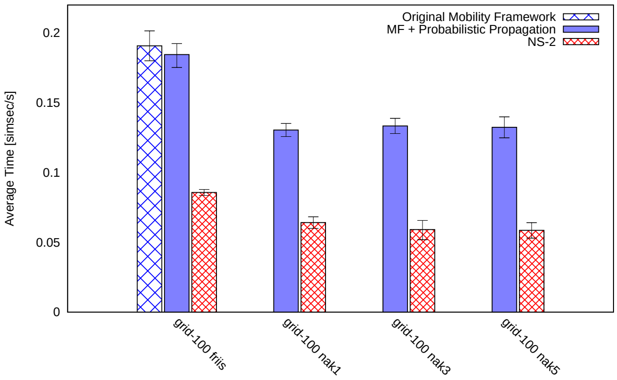

Figure 10: Simulation speed in terms of simulated seconds per real second for the grid topology and 100 senders

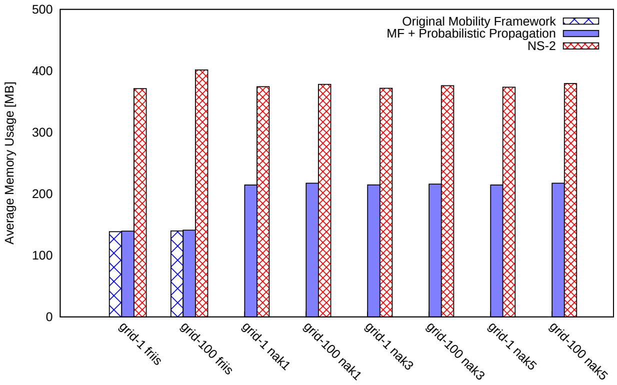

Figure 11: Memory usage in the grid topology scenarios

In future work we will address the calculation of maximum propagation distance for the Nakagami model with the m-parameter being greater than 1. Furthermore, the analytical results should be derived for other propagation models. Also, an improved modeling of multiple interfering events with respect to maximum propagation distance is still left open and will need further analytical and simulative investigation.

8. ACKNOWLEDGEMENTS

This work was partially supported by the German Research Foundation (DFG) within the Research Training Group GRK 1194 ”Self-organizing Sensor-Actuator Networks”.

9. REFERENCES

[1] Network simulator NS-2. http://www.isi.edu/nsnam/ns/.

[2] Q. Chen, F. Schmidt Eisenlohr, D. Jiang, M. Torrent Moreno, L. Delgrossi, and H. Hartenstein. Overhaul of IEEE 802.11 modeling and simulation in ns-2. In *MSWiM ’07: Proceedings of the 10th ACM international symposium on modeling, analysis, and simulation of wireless and mobile systems*, pages 159–168, New York, NY, USA, 2007. ACM.

[3] D. Kotz, C. Newport, R. S. Gray, J. Liu, Y. Yuan, and C. Elliott. Experimental evaluation of wireless simulation assumptions. In *MSWiM ’04: Proceedings of the 7th ACM international symposium on modeling, analysis and simulation of wireless and mobile systems*, pages 78–82, New York, NY, USA, 2004. ACM.

[4] M. Nakagami. The *m*-distribution — A general formula for intensity distribution of rapid fading. In W. G. Hoffman, editor, *Statistical Methods in Radio Wave Propagation*. Pergamon, Oxford, U.K., 1960.

[5] OMNeT++ Community. *OMNeT++ Community Site — Simulation Models*, 12 2007. http://www.omnetpp.org.

[6] T. S. Rappaport. *Wireless Communications: Principles & Practise*. Prentice Hall Communications Engineering and Emerging Technologies Series. Prentice Hall PTR, Upper Saddle River, NJ 07458, 1996.

[7] F. Schmidt Eisenlohr, J. Letamendia Murua, M. Torrent Moreno, and H. Hartenstein. Bug Fixes on the IEEE 802.11 DCF module of the network simulator ns-2.28. Technical Report TR-2006-1, Department of Computer Science, University of Karlsruhe, 2006.

[8] V. Taliwal, D. Jiang, H. Mangold, C. Chen, and R. Sengupta. Empirical determination of channel characteristics for DSRC vehicle-to-vehicle communication. In *VANET ’04: Proceedings of the 1st ACM international workshop on vehicular ad hoc networks*, pages 88–88, New York, NY, USA, 2004. ACM.

[9] V. Turau, C. Renner, M. Venzke, S. Waschik, C. Weyer, and M. Witt. The heathland experiment: results and experiences. In *Proceedings of the REALWSN’05 workshop on real-world wireless sensor networks*, Stockholm, Sweden, 2005.