On the Way to a More Realistic Simulation Environment for Mobile Ad-hoc Networks

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Abstract: Two main steps on the way to more realistic simulations of mobile ad-hoc networks are the introduction of realistic mobility and sophisticated radio wave propagation models. Both have strong impact on the performance of mobile ad-hoc networks, e.g. the performance of routing protocols changes with these models.

In this paper we introduce a framework which combines realistic mobility and radio wave propagation models. Our approach consists of a mobility generator and an obstacle model for the radio wave propagation. It enables researchers to create realistic simulation setups and thus helps to correctly evaluate new algorithms and protocols. For the mobility generation a wide variety of well understood random mobility models is combined with a graph based zone model, where each zone has its own mobility model. To achieve a realistic radio wave propagation model a ray-tracing approach is used. The integration of these two techniques allows to create simulation setups that closely model reality.

1 Introduction

A mobile ad-hoc network [IET02] is created by a collection of nodes which communicate using radio interfaces and do not rely on any pre-installed infrastructure. Furthermore, it is supposed that ad-hoc networks are inherently adaptive and auto-configured. Therefore, ad-hoc networks offer immense flexibility.

In recent years the interest in the deployment of ad-hoc networks for real world scenarios grew. Still the number of real world ad-hoc networks is quite low and most of the testbeds [GB04] consist only of a small number of nodes. The development and testing of new algorithms and methods nowadays relies heavily on network simulations. Simulating wireless networks, and especially mobile ad-hoc networks, is not a trivial task and consequently there have been discussions about the validity of presented simulation results [KNG+04, PJL02]. This work does not deal with the methodological background used to analyze the output of the simulation, instead it deals with the question how accurate the simulation output is. It is argued here that the mobility and the radio wave propagation models have an important impact on simulation results accuracy.

Therefore, it is of great importance for researchers to better understand the implications and influences of all parts of the simulation environment. In this paper, two basic components for every MANET simulation are discussed in more detail: The mobility model which describes how the nodes move within the simulation area and the radio wave propagation model which defines how the radio transmission takes place between nodes. The traffic model, which is an equally important part of the simulation environment is not yet covered here, but it is about to be added.

In the past, very simplistic random mobility models were used to generate node movements. It has been shown before, that these models yield unrealistic behavior [BHPC02, BRS03]. One reason for this is, that movement patterns of humans are much more complex and cannot be modelled by only one of these random models.

Yet, it is stated here, that the well known and analyzed models can be used to model smaller parts of the simulation setup e.g. the random direction model can be useful to generate movements for pedestrians on inner-city places, but it is not suited well to model cars on a street.

The second component with which we are dealing is the radio wave propagation model. The impact of the radio wave propagation model on the simulation results is obvious. In most currently available network simulators nodes are assumed to have a circular transmission range with fixed radius, independent of the current location of the communicating nodes. This might be realistic in open spaces, but it is certainly not true in buildings or in a city. Simplified propagation models will yield much better simulation results than achievable in reality.

Taking the publications of the MobiHoc conferences of the last two years as an example, it is obvious that there is a need for better tool support for simulation designers. Out of 52 papers 35 presented simulation results (around 67%). Six papers did not give any information about the used mobility model, 10 used *random waypoint* to model mobility and 14 considered static scenarios. Only two papers showed results obtained from considering more than one mobility model. Examining the used radio wave propagation model, the findings are even more suprising: only two papers mention the used radio wave propagation model, ten paper gave no indication about the used model and 22 used a fixed radius. Assuming that all papers which did not specify their propagation model used a fixed range it can be concluded that all papers used circular, bidirectional links. None of the presented papers used a small scale (fading) model.

Our contribution in this work is an integrated framework which allows to generate mobility patterns based on a zone and obstacle model. A movement zone characterizes a certain geographical area and has several properties including mobility model, population, and exit probability. Mobile nodes move on a zone according to its properties. All zones together establish a directed and weighted graph, where the weight of a directed edge specifies the rate with which nodes move from one zone to a neighbor zone. This graph is used to generate the node movements. An obstacle is defined by a geometric region and its reflection and transmission properties. The reflection property defines how much of the radio wave is reflected and the transmission property defines the fraction of power which is transmitted through an obstacle. A graphical tool to build the scenario and to create the movement and radio wave propagation data has been developed.

The remainder of the paper is structured as follows: In Section 2 existing mobility and radio wave propagation models are presented. In Section 3 the framework is discussed in more detail and in Section 4 generated scenarios are evaluated and simulation results obtained with ns-2 are discussed.

2 Related Work

In this Section we first describe commonly used random mobility models. Subsequently, radio wave propagation models are briefly described and existing ray-tracing approaches are discussed.

The mobility models proposed in literature can be generally distinguished in two classes: i) entity mobility models, and ii) group mobility models. Detailed descriptions of commonly used random mobility models and their impacts on ad-hoc network simulation is given in [HGPC99, CBD02, San05, BSH03, LNR04].

2.1 Entity random mobility models

The most simple random mobility model is called Random Walk, also known as Brownian motion. In this model, a mobile node selects randomly a direction and speed from predefined ranges $[\varphi_{\text{min}} : \varphi_{\text{max}}]$ and $[v_{\text{min}} : v_{\text{max}}]$, respectively. Each movement is bounded either by travel time or by travel distance. There are many variants of this model.

The Random Waypoint mobility model is an extension of Random Walk and integrates a pause time between two consecutive moves. A mobile node stays after a movement a certain time period t_{pause} at the destination location. A disadvantage of this model is the concentration of nodes in the center of the simulation area. To overcome this problem the Random Direction model enforces nodes to move until they reach the border of the simulation area.

Unfortunately, in these mobility models nodes have sharp direction changes which does not fit to the movement behavior of humans. The main reason for this discrepancy from reality is that these models are memoryless, i.e. a node does not consider the visited locations when selecting the next one.

The Gauss-Markov model prevents the problem of sharp direction changes by considering the most recent moves into the calculation of the next destination. Therefore, the resulting movement pattern is more smooth.

Beside these 'plain area' models, there are also some models which try to map the characteristics of car movements on streets. In the Freeway model, there is at least one lane in each direction of a street. The mobile nodes move on the lanes. The speed of a mobile node depends on other nodes on the same lane. The Manhattan model is similar to the Freeway model. The lanes are organized around blocks of buildings. A mobile node can change its direction only at intersections.

2.2 Group random mobility models

The mobility models discussed in the previous section describe the movement of only one mobile node. Sometimes, the movement of a mobile node depends on the movement of other nodes. The group mobility models specify how a set of mobile nodes move in respect to each other.

In the Column Mobility Model, a group of nodes build a line and move uniformly to a destination. In the Nomadic Community Mobility Model, all mobile nodes move to the same location in the same order but by using different entity mobility models. In the Pursue Mobility Model, the movement of a group is determined by a target. The Reference Point Group Mobility model specifies the movement of the group as well as the movements of the nodes within the group.

2.3 Obstacle mobility model

All mobility models discussed so far share the assumption that there are no obstacles, i.e. each point on the simulation area can be occupied by a mobile node. This is especially disturbing if you want to map the movements to real locations like a city or university campus. In the real world movement paths' are restricted on certain ways or streets.

In [JBRAS03] a refinement of random mobility models by integrating obstacles is proposed. The obstacles represent buildings. Upon the definition of buildings, pathes between them are calculated. The mobile nodes are randomly distributed on the pathes and the destinations of the nodes are selected randomly among the buildings. The nodes move on the defined paths from building to building. Additionally, the radio propagation is affected by the obstacles. It is assumed that radio signals are completely blocked by obstacles. Hence a mobile node inside a building cannot communicate with a mobile node outside the building. Thus, the used radio propagation model is very simplified.

2.4 Radio Wave Propagation

Radio channels are more complicated to model than wired channels. Their characteristics may change rapidly and randomly and they are dependant on their surrounding (buildings, terrain, etc.). Nevertheless, most wireless network simulators use very simplified propagation models. In general, propagation models can be characterized into two groups: large-scale and small-scale propagation models. Large-scale models characterize how the transmission power between two nodes changes over long distances and over a long time. Small-scale models account for the fact that small movements (in the order of the wavelength) may have large influence on the transmission quality. Also, due to multipath propagation, the signal varies heavily even if the nodes do not move. Small-scale propagation models are often called fading models.

Most commonly used propagation models are the Free Space model, the Two-Ray Ground model and the Shadowing model [Rap99]. In addition, Ricean an Rayleigh fading are often used as small-scale models [PNS00].

All these models share the common property that their transmission range is roughly circular and that the transmission is not dependent on the current location. None of these models is able to correctly model complex scenarios with obstacles. One possibility to overcome this limitation is the use of ray-tracing technologies known mainly from computer graphics. In [DD04] an approach using this technique is described. It allows to define obstacles in a graphical editor and this scenario description is used in the simulation to feed a ray-tracing algorithm. The algorithm is started once for every new position the node takes up. The authors state that this approach slows down the simulation by a factor of up to 100. Also, no movement information is generated by this tool.

Our work overcomes this limitations by generating the movement data and the ray-tracing input files needed for the simulation. By this, it enables researchers to easily create complex scenarios and simulation setups. It is also possible to use only parts of the generated data: in Sec. 4 simulation studies are presented which use different combinations of input data for the simulation. The following sections details the scenario creation process and explains the generation process for the movement files and the volume maps for the radio wave propagation.

3 Generation Framework

In this Section we introduce CosMos – The Communication Scenario and Mobility Scenario Framework. CosMos is a general framework for the design of realistic simulation scenarios for mobile ad-hoc networks by integrating mobility models, propagation models, and communication models.

We have realized CosMos in C++/Qt. It implements the mentioned features, namely creating scenarios using a graphical editor, generating movement data, and calculating the radio wave propagation using a ray-tracing algorithm. The goal is to show the impact of mobility and radio wave propagation on the result of MANET studies and to give researchers an easy-to-use tool to create own scenarios.

3.1 The World of CosMos

The main building block of CosMos are zones: *movement zones* and *obstacle zones*. A mobility model is assigned to each movement zone and radio wave propagation parameters to every obstacle zone. Among the movement zones a neighborhood relationship is defined, which is set explicitly by the user. CosMos builds a directed and weighted graph $G(V, E)$ with zones as nodes and the neighborhood relationship as weighted and directed edges. The weight $w_{i,j}$ of a directed edge $e_{i,j} \in E$ from zone i to zone j specifies the rate with which nodes move from zone i to zone j. The higher the weight $w_{i,j}$ the higher the

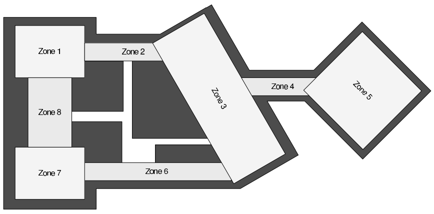

Figure 1: Environment Setup for CosMos.

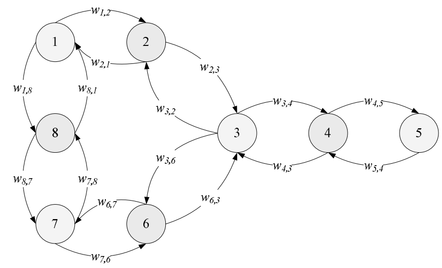

Figure 2: Graph View of the Environment.

probability that zone j is chosen as destination for a node.

Furthermore, our approach allows the calculation of the spatial distribution of nodes on the simulation area as well as the distribution of the nodes on the defined zones. This allows us to figure out the time when the stationary state is reached. Since, trustworthy MANET simulations should begin when the stationary state is reached.

Figure 1 shows a schematic view of the world of CosMos. The directed and weighted graph for the example in Figure 1 is depicted in Figure 2. In this specific case it is assumed that the zones connecting the places are assigned the Freeway model with one lane in each direction. The different zones are depicted there. The yellow and green ones are movement zones with different mobility models, the red ones are obstacles.

3.2 Scenario Creation

The workflow for CosMos is depicted in Figure 3. First you need to create a scenario definition file. This is done using the graphical frontend of CosMos. A scenario consists of several zones. Zones are either movement zones or obstacles. A mobility model is assigned to each movement zone. The model is given its own set of parameters (e.g. maximum speed) and a certain exit probability. The obstacles are set up with alpha and reflection values and with a height. A scenario also needs *starting points* for the ray-tracer.

The idea behind decomposing the simulation area into a number of smaller areas with their respective mobility models is that the existing mobility models model only parts of the reality. Imaging a man traveling from his home to his working place. First he will walk to his car, then drive towards the freeway, follow the freeway to his destination exit, then drive through an inner-city area, and finally walk to his working place. His movements on each of the mentioned parts of the journey can be characterized by a specific mobility model, but his complete journey cannot be modelled with only one model.

Similar, he crosses several environments which have different properties for the radio wave propagation model. The area around his home may be sparsely covered with buildings, whereas the inner-city area will be dominated by large concrete buildings. Such environ-

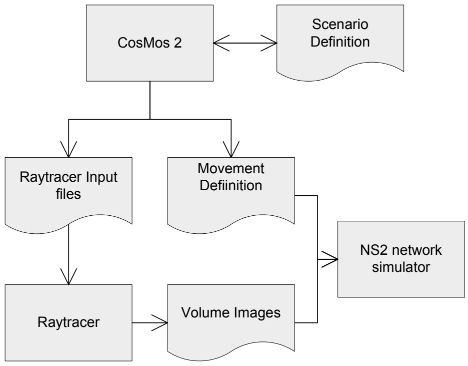

Figure 3: Workflow using CosMos

ments are modelled very badly with common radio wave propagation models.

The creation of complex scenarios is a difficult and time consuming task. That is one reason why most of the presented simulation studies still use the random waypoint mobility model and the TwoRay Ground propagation model. To ease the creation of more complex scenarios, CosMos offers a graphical user interface which allows fast building of the scenario. Movement zones and obstacles can be created by drawing them with the mouse and assigning them the needed properties. Currently, we are in the process of creating a database of existing scenarios. The scenarios will be available for download on our website [mcg].

3.3 Movement Data Generation

CosMos per default creates several independent variants of the movements according to the given models. This helps the researcher to conduct simulations with independent replications. In the beginning, all nodes are placed randomly within the zones. The distribution is weighted with the area of the zones: The larger the zones, the higher the probability for every node to be placed there. Then each node's movements are calculated according to the mobility model in its zone. If, according to the exit probability, the node is supposed to leave its zone, the destination zone is calculated according to the weighted graph. The node is then moved to a randomly selected destination within the handover zone of the old and the new zone. The node is deregistered in the old zone and registered in the new zone. After that, movements are generated according to the new zone's mobility model[1]. This method of handing over a mobile node from one zone to another zone requires the slight modification of the used random mobility models. The last target location of the mobile node in zone i has to be on the handover area and the first location on zone j has to be

[1]The handover is currently not used in the simulation process but it could be used to trigger network layer handoffs during the simulation.

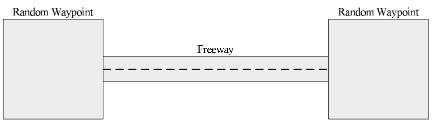

Figure 4: Setup of the example scenario.

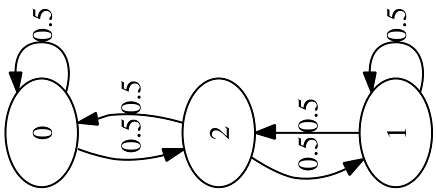

Figure 5: Weighted and directed graph of the example scenario for a particular setting.

exactly this location on the handover area. The slight modification of the used random mobility models in our implementation is not a big issue and does not change the general behavior of these mobility models. Accordingly, movements in CosMos can be characterized into *intra-zone* mobility and *inter-zone* mobility. The intra-zone mobility depends on the zone's mobility model and the inter-zone movement depends on the exit probability and the weighted graph. CosMos offers a special kind of mobility model used only to connect zones: If a node enters a zone using this mobility model, one of the neighbors of the zone is selected and the node moves directly to the selected one.

Example

An example scenario for the generation of movement files is presented here. Two places of size 500 $\times$ 500 m^2 with a distance of 1000 m are defined. Figure 4 shows the map of the scenario and Figure 5 shows the directed and weighted graph of this scenario for a particular setting. The nodes 0 and 1 depicts the both places and node 2 depicts the the connecting zone. Both of the two places are assigned the Random Waypoint model and the connecting street is assigned the Freeway model.

When talking about mobility models two characteristics are of particular importance. The spatial distribution of the nodes on the simulation area and the distribution of the nodes on the mobility zones. Figure 6 depicts the spatial distribution of the nodes and Figure 7 depicts the distribution of the nodes on the mobility zones for the presented example. These results are based on the setting where all probabilities are set to 0.5 like in Figure 5. The typical characteristic of the Random Waypoint mobility, i.e. the accumulation of the nodes in the center of the simulation area, is obvious for both of the places in Figure 6. The probability to meet a node is higher on the both places than on the connecting street. The reason for this is, that all nodes entering the street leave the street either to one of the places. Figure 7 shows the fraction of nodes as a function of the simulation time for each of the three zones. We have run the mobility model for 10000 s. The transient phase of the simulation lasts around 2000 s. During this time the number of nodes in each of the zones varies. After this time the mobility enters a stationary state. The network simulation should start after the stationary state is reached.

To get a better idea about the spatial distribution, the distribution of the nodes, and the transient and stationary state we present here a variant of the example. We changed the

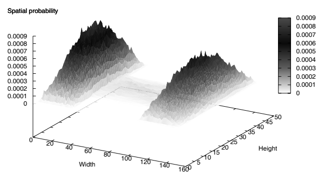

Figure 6: Spatial distribution of the nodes.

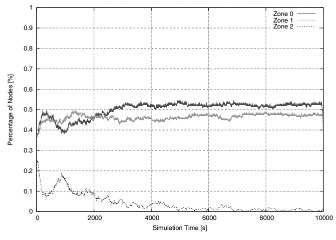

Figure 7: Distribution of the nodes on the zones.

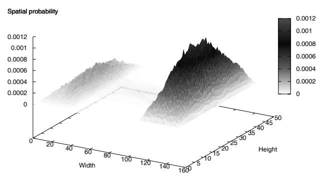

Figure 8: Spatial distribution of the nodes.

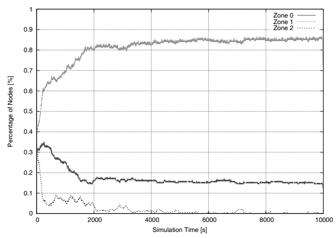

Figure 9: Distribution of the nodes on the zones.

exit probability from 0.5 to 0.2 for the place on the right side. Thus the probability that a node leaves the place on the right side is smaller and we expect that more nodes will be on this zone. Figure 8 depicts the spatial distribution for this case and Figure 9 shows the distribution of the nodes on all zones as a function of the simulation time. From Figure 8 is obvious that the characteristic of the Random Waypoint model is still kept, but the intensity is changed. The probability to meet a node is different on both of the places, it is higher on the place on the right side and lower on the place on the left side. Thus, the number of nodes on the right side must be higher. This assumption is confirmed by Figure 9. During the transient phase, which lasts again around 2000 s, of the mobility model the fraction of nodes in each of the zones varies. After reaching the stationary state the node distribution is stable. Nearly 85% of the nodes are on the place on the right side and the remainder of the nodes are on the both other zones.

3.4 Radio Wave Propagation

The radio wave propagation model used in this work is based on a ray-tracing approach. The obstacles defined in CosMos are used as input for the ray-tracer. Triggering a ray-tracing run for every position of the current sender is unfeasible in mobile ad-hoc networks.

Instead, our approach uses a set of predefined *starting points* for the ray-tracing approach. The ray-tracer is then started once for each of this points creating an energy distribution map for each one. During the simulation the energy distribution between the sender and the receivers is calculated using weighted interpolation, as detailed below. The ray-tracer accounts for the following propagation phenomenas: reflection, diffraction, and scattering.

To use the generated energy distribution maps during the simulation, we modified the ns-2 network simulator [FV03]. We added a propagation model which reads in a given set of maps and the corresponding starting points. During the simulation, whenever a node n_t wants to transmit a packet, a k-nearest neighbor search is started[2]. This search finds the k nearest starting points and their corresponding energy distribution maps to the sender's position. For each node inside the maximum interference range of an unobstructed radio wave the transmission power is calculated. The formula used for the weighted interpolation is given below:

$$s_{t-r} = \frac{\sum_{i=0}^{k-1} \frac{s_i}{\|pos_i - pos_t\|^p}}{\sum_{i=0}^{k-1} \frac{1}{\|pos_i - pos_t\|^p}},$$

where s_{t-r} is the signal strength between the transmitter node n_t and the receiver node n_r. The position of the transmitter is given as pos_t, pos_i denotes the position of the starting point of the i-th closest map. Note that s_i is the predicted signal strength of map i at the position of the receiver pos_r. The exponent p controls how much influence is given to further away maps[3].

The benefits of our approach are that it is not necessary to rerun the ray-tracing algorithm during simulation time, it is not necessary to divide the simulation area into evenly sized squares, and the accuracy can be increased in areas with a lot of obstacles, simply by adding more points. A real-time evaluation tool has been developed to show the result of the interpolation. Our approach increases the simulation speed and allows the designer to choose between high accuracy and reduced memory needs [SW06].

4 Results

In this Section we discuss some simulation results created with ns-2. The simulation scenarios were created with CosMos. To show the flexibility of CosMos, two scenarios are presented: One models the inner-city area of Aachen, the other one models the office building our chair is in. The intention of the studies was to show the impact of the mobility and radio wave propagation models on the performance of MANET routing protocols.

[2]Our experiments showed k equal to 3 gave good results.
[3]In our experiments p was set to 3.

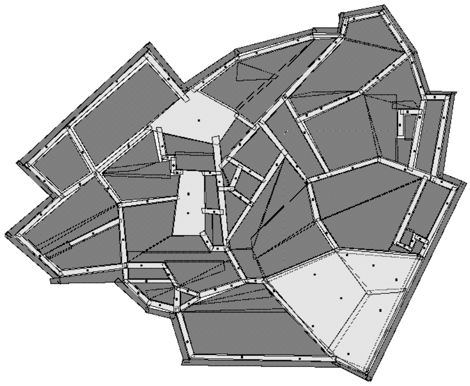

Figure 10: Aachen Scenario

4.1 Outdoor scenario

We selected the downtown of Aachen, Germany, as the target location. All simulation parameters like velocity, the number of mobile nodes, the sizes and the number of zones, and the number of connections are chosen carefully to set up the simulation as adequate as possible. Our knowledge about the local conditions flew into the design of the simulation scenario. Figure 10 depicts the simulation scenario with a screenshot of CosMos. CosMos allows to load a graphic file as background image. We choosed a map of Aachen and thus were able to adequately model the movement zones and the obstacles. In Fig. 10 the movement zones are depicted in light gray and the obstacles are colored in dark gray.

The following simulation setups were considered: Random Waypoint mobility model combined with Two-Ray Ground propagation model, CosMos mobility model together with Two-Ray Ground propagation model, and CosMos propagation model with ray-tracing propagation model.

The simulation area is in all cases $612 \times 493m$, all nodes are equipped with IEEE 802.11 radio interfaces with a transmission rate of 11Mbit/s and a transmission power of 0.1 mW. The receiving threshold was set to -88dBm, a value taken from the specification of the Cisco Aironet 1240AG Series access point. The AODV implementation of the university of Uppsala was used. Thirty connections between randomly selected nodes were started, each one offering 32kBytes of load.

Figure 11 shows the average number of hops needed for the communication. The simulations using Random Waypoint (RWP) and Two-Ray Ground (TRG) show the highest number of nodes. This is due to the fact that nodes are relatively sparse (compared to the CosMos scenario, see Table 1) because of the unrestricted movement on the simulation area. Nevertheless the simulation area is relatively small compared to the transmission range of the nodes. Using RWP together with TRG results in the following: nodes are able to communicate over relatively stable long paths. Opposed to that, the paths used

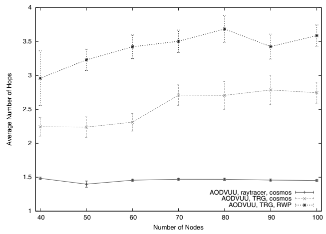

Figure 11: Number of hops between the source and destination node of a connection

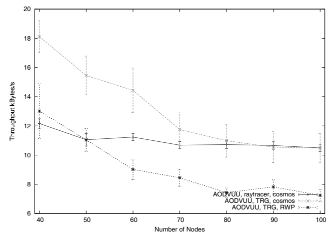

Figure 12: Throughput as function of the number of nodes in the network

Table 1: Node densities for scenarios with and without restrictions

Number of nodes	50	60	70	80	90	100
Node density RWP $\times 10^{-4}$	1.66	1.99	2.32	2.65	2.98	3.31
Node density CosMos $\times 10^{-3}$	1.12	1,35	1.57	1.80	2.02	2.24

when CosMos movement and the ray-traced propagation model is used are much shorter, because longer paths cannot be build up due to the more accurate propagation model. CosMos movement combined with TRG propagation results in smaller average hop count because of the higher node density. Table 1 shows the node density for the used simulation area. CosMos restricts the movements to a smaller part of the simulation area, hence the node density in these part is up to one order of magnitude higher than in the unrestricted case.

Figure 12 shows the average throughput per successful connection. As expected, the average throughput is lowest for the RWP+TRG scenario because the routes were longer in average. The simulations using the cosmos mobility model and the TwoRay Groung propagation model showed the highest average throughput. If the ray-traced propagation model is used, the throughput stays nearly constant. Only nodes which were relatively close to each other were able to transmit.

4.2 Indoor scenario

Figure 13 shows the second scenario. It models the floor plan of the building of the computer science center in Aachen. Only the ground floor is modeled here. This environment differs from the outdoor scenario in several ways. First of all, it is much smaller which should be refelected in the simulation results. Secondly, the movement pattern differs from

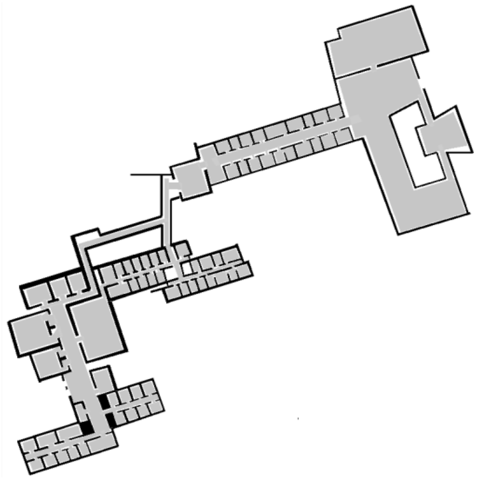

Figure 13: Indoor scenario

the outdoor scenario. Movements inside of offices are seldom and relatively slow (max. speed was set to $1\,m/s$). Movements inside of the hallways on the other hand are faster and follow the freway model (max. speed was set to $2\,m/s$). The largest difference compared to the outdoor scenario is the granularity of the obstacles. Since we had detailed plans of our building, we were able to model it with high detail.

We conducted simulations using the AODV and the DSR routing protocols. The traffic model was similar to the one used for the outdoor scenario. Figure 14 shows a comparison of the throughput achieved using AODV and DSR in the presented scenario. It is clear to see that the measured values without the ray-tracer propagation model can be considered as equal. But using the ray-traced propagation model, the DSR protocol suffers more heavily from performance loss. AODV seems to be able to cope better with the situation. The decreasing performance for larger number of nodes can be explained by the higher number of hops between sender and destination. The routes are getting longer because the node density is higher and farther away nodes can also be reached. The reason for the worse performance of DSR compared to AODV seems to be a larger number of discovered paths which were actually already invalid when they should be used for the first time.

Figure 15 compares the average end-to-end delay for packets between source and destination. As expected, the values using TwoRay Ground can again be considered as equal. Using the ray-tracer the delay of course grows due to longer routes, higher number of transmission errors, and thus higher routing overhead. Again, we see a strong influence on DSR. As a rule of thumb, one can say that if more than 90% of all packets have a delay of less than 150ms, VoIP is possible with reasonable quality. If scenarios with more than 60 nodes are considered, DSR is not able to fullfil this criterion. This is yet another example why accurate simulation models are absolutely neccesarry. If one would have based the decission on the simple simulation setup both algorithms would have been judged as equal

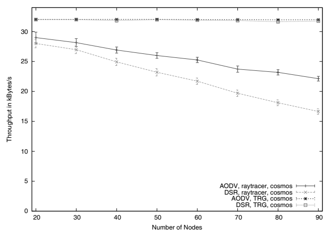

Figure 14: Throughput comparison between AODV and DSR

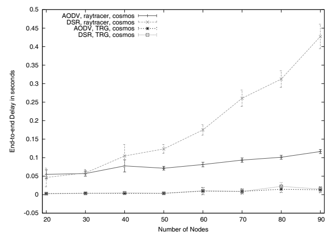

Figure 15: Delay comparison between AODV and DSR

Table 2: Runtime of the ns-2 simulator.

Number of nodes	Runtime (s) TwoRayGround	Runtime (s) PhotonPropagation	Factor
10	13.6	16.5	1.2
20	34.3	61.9	1.8
30	59.3	91.1	1.5
40	69.1	119.2	1.7
50	90.2	147.5	1.6

but in reality only AODV is actaully able to fullfil the delay bound.

Another result of our simulation study is that the mobility model is more important for larger scenarios. The smaller the simulation area compared to the transmission range of the nodes, the smaller the influence of the mobility model. We also measured the run-time of the simulations with and without our propagation model. Table 2 shows the times for the indoor simulation. The increase in run-time is relatively small since during the simulation runtime only lookups in the kd-tree have to be done. The preprocessing time, namely the time needed to create the energy distribution maps, is dependant on the complexity of the scenario. For the presented indoor scenario 112 starting points were used and the ray-tracer needs around 12 seconds for each point (shooting 50000 photons).

5 Conclusions

The mobility model and the radio wave propagation model are very important components of mobile ad-hoc network simulations. Each component on its own has strong influence on the network topology and therefore a strong influence on the overall network performance. A combination of these two components is one large step towards more realistic simulation environments.

In this paper we have introduced a mobility and radio wave propagation scenario generator for mobile multi-hop ad-hoc networks. The goal was to aid researchers in the design of 'realistic' simulation scenarios. The framework is very general and can be deployed to design scenarios with special requirements. Our approach combines a wide variety of well understood random mobility models with a graph based zone model and a sophisticated ray-traced radio wave propagation model. Each zone can have a different mobility model. The framework allows to generate the mobility definition and the ray-tracer results from one common scenario. So the combination of realistic movement models and accurate radio wave propagation models becomes an easy task for the researcher. Besides the simple scenario which consists of only one rectangle zone and no obstacles and a particular number of nodes, we are interested in the design of scenarios which emulate a city or a working place. The complex scenarios require the combination of several mobility models and obstacles with different properties. Furthermore, our approach allows the calculation of the spatial distribution of nodes on the simulation area as well as the distribution of the nodes on the defined zones. This allows us to figure out the time when the stationary state is reached. Since, trustworthy MANET simulations should begin when the stationary state is reached.

References

[BHPC02] Christian Bettstetter, Hannes Hartenstein, and Xavier Perez-Costa. Stochastic properties of the random waypoint mobility model: epoch length, direction distribution, and cell change rate. In *MSWiM '02: Proceedings of the 5th ACM international workshop on Modeling analysis and simulation of wireless and mobile systems*, pages 7–14, New York, NY, USA, 2002. ACM Press.

[BRS03] Christian Bettstetter, Giovanni Resta, and Paolo Santi. The Node Distribution of the Random Waypoint Mobility Model for Wireless Ad Hoc Networks. *IEEE Trans. Mobile Computing*, 2(3):257–269, July–September 2003.

[BSH03] Fan Bai, Narayanan Sadagopan, and Ahmed Helmy. The IMPORTANT Framework for Analyzing the Impact of Mobility on Performance of Routing for Ad Hoc Networks. *AdHoc Networks Journal - Elsevier Science*, 1(4):383–403, November 2003.

[CBD02] Tracy Camp, Jeff Boleng, and Vanessa Davies. A Survey of Mobility Models for Ad Hoc Network Research. *Wireless Communications and Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications*, 2(5):483–502, 2002.

[DD04] J.-M. Dricot and Ph. De Doncker. High-accuracy physical layer model for wireless network simulations in NS-2. In *Proceedings of the International Workshop on Wireless Ad-hoc Networks*, 2004.

[FV03] K. Fall and K. Varadhan. The ns-2 manual. Technical report, The VINT Project, UC Berkeley, LBL and Xerox PARC, 2003.

[GB04] Mesut Güneş and Imed Bouazizi. From Biology to Technology: Demonstration Environment for the Ant Routing Algorithm for Mobile Ad-hoc Networks. In *Tenth Annual International Conference on Mobile Computing and Networking (ACM MobiCom 2004)*, Philadelphia, USA, September 2004.

[HGPC99] X. Hong, M. Gerla, G. Pei, and C.-C. Chiang. A Group Mobility Model for Ad Hoc Wireless Networks. In *Proceedings of the ACM International Workshop on Modeling and Simulation of Wireless and Mobile Systems (MSWiM)*, pages 53–60, August 1999.

[IET02] IETF Working group MANET. Mobile Ad-Hoc Networks (manet) Charter, 2002.

[JBRAS03] Amit Jardosh, Elizabeth M. Belding-Royer, Kevin C. Almeroth, and Subhash Suri. Towards Realistic Mobility Models For Mobile Ad hoc Networks. In *The Ninth Annual International Conference on Mobile Computing and Networking (ACM MobiCom 2003)*, San Diego, USA, September 14-19 2003. ACM.

[KNG+04] David Kotz, Calvin Newport, Robert S. Gray, Jason Liu, Yougu Yuan, and Chip Elliott. Experimental evaluation of wireless simulation assumptions. Technical Report TR2004-507, Dept. of Computer Science, Dartmouth College, June 2004.

[LNR04] Guolong Lin, Guevara Noubir, and Rajmohan Rajaraman. Mobility Models for Ad hoc Network Simulation. In *Proceedings of the 23rd Conference of the IEEE Communications Society (INFOCOM)*, Hon Kong, March 7-11 2004. IEEE, IEEE.

[mcg] Website of the mobile communication group.

[PJL02] Krzysztof Pawlikowski, Hae-Duck Joshua Jeong, and Jong-Suk Ruth Lee. On Credibility of Simulation Studies of Telecommunication Networks. *IEEE Communications*, 40(1):132–139, January 2002.

[PNS00] Ratish J. Punnoose, Pavel V. Nikitin, and Daniel D. Stancil. Efficient Simulation of Ricean Fading within a Packet Simulator. In *Vehicular Technology Conference*, September 2000.

[Rap99] Theodore S. Rappaport. *Wireless Communications, Priciples & Practice*. Prentice Hall, 1999.

[San05] Miguel Sanchez. Mobility Models, 2005.

[SW06] Arne Schmitz and Martin Wenig. The effect of the Radio Wave Propagation Model in Mobile Ad Hoc Networks. In *MSWiM '06: Proceedings of the 9th ACM international workshop on Modeling, Analysis and Simulation of wireless and mobile systems*, New York, NY, USA, 2006. ACM Press.