Efficient and Realistic Mobility and Channel Modeling for VANET Scenarios using OMNeT++ and INET-Framework*

Robert Nagel
Institute of Communication Networks
Technische Universität München
D-80290 München
robert.nagel@tum.de

Stephan Eichler
Institute of Communication Networks
Technische Universität München
D-80290 München
s.eichler@tum.de

ABSTRACT

Mobility and channel modeling is a very crucial task for the simulation of Vehicular Ad Hoc Network (VANET) scenarios. In this paper we present a new mobility modeling approach for OMNeT++ and the INET-Framework. The approach allows generation and deletion of nodes during simulation time and reduces the number of events significantly. To demonstrate and test the functionality of the new modeling concept we designed a simple, yet effective mobility model called Manhattan Grid Mobility Model (MGMM), which can be coupled with a new channel modeling approach, incorporating obstacles such as buildings for the reception power calculation. In our paper we describe both, the general concept of our idea, the realization using the MGMM and the Dual-Slope channel model, and give an overview on related work.

Keywords

Mobility modeling, channel model with obstacles

1. INTRODUCTION

Research in the field of wireless networks is often based on a network simulator which usually models the full stack of the network nodes. Hence, not only the protocol or scheme under test needs to be simulated, but also supporting models are required to generate sound results for the respective environment. Typical examples for supporting models in the Mobile Ad Hoc Network (MANET) research field are mobility behavior and radio channel aspects.

Since these supporting models are very crucial to replicate the real characteristics of the scenario, they can not be omitted. However, each additional model adds to the complexity of the simulation scenario and increases the required time for a simulation run. Hence, these models have to be carefully designed to be efficient and scalable, otherwise the entire scenario model can not be handled in settings with several hundreds of nodes. The performance and scalability of a model is determined by three main factors: The number of events generated, the memory requirements, and the processing time of the model. Moreover, some supporting models have interdependencies, hence, making one model more sophisticated while leaving the depending models unchanged, can lead to misleading simulation results.

In this paper we introduce a new modeling technique for node mobility in the context of OMNeT++ and the INET-Framework. The new modeling approach helps to significantly reduce the number of events required for mobility modeling, especially in large scale scenario settings. In addition, we present a new mobility model using this new approach, the Manhattan Grid Mobility Model (MGMM). Many different mobility modeling approaches have been suggested especially for Vehicular Ad Hoc Network (VANET) scenarios over the last few years. But many of these concepts are very ressource intensive, thus, they lead to long execution times even for simple scenarios with less than 100 nodes. The idea behind the MGMM was to find a compromise between complexity and precision. Further, we wanted to increase the precision of the model interdependencies. Therefore, we combined the new mobility model with a channel model aware of obstacles such as buildings. Usually, channel models taking into account obstacles require lots of processing power (e.g. ray-tracing). To efficiently handle even large scenario settings containing several hundred obstacles a segmentation approach using the Binary Space Partitioning (BSP) algorithm is used in our concept.

The remainder of the paper is organized as follows. In Sec. 2 the specific simulation scenario and its requirements are introduced, motivating the need for the new models. In Sec. 3 the mobility modeling approach and the MGMM are presented. The new channel model is detailed in Sec. 4. The evaluation of the new models and a comparison with the well-known Random Waypoint Model (RWM) are presented in Sec. 5. Before the paper closes with conclusion remarks we present the related work in Sec. 6.

2. SPECIFIC SIMULATION SCENARIO AND REQUIREMENTS

Existing mobility models such as the Random Waypoint Model or the Random Direction model are sufficient in their functionality for most general wireless simulation scenarios. However, especially in the context of Vehicular Networks (VNs) like VANETs or networks of cognitive automobiles [18],

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these models do not reproduce the mobility of vehicles sufficiently enough. Therefore, new models are required which provide realistic vehicle behavior while still being simple enough to have a high performance.

The most important criterion for the new group of mobility models is that nodes no longer move in a random fashion. However, nodes shall move on predetermined roads. The definition of the road map can be done by the model itself or by using genuine digital maps. The modeling of the vehicle movement along these roads has to be controlled by the model. The simplest solution is to assign a vehicle speed to each node, like it is done in most elementary random models. More sophisticated models would generate a real vehicle behavior, with vehicle acceleration and interaction like presented by Krauß et al. in [11], which is used in the SUMO simulator [10].

For several scenarios and protocol evaluations the capability to be able to generate new nodes during simulation runtime is crucial besides the mobility modeling of each vehicle. Hence, the simulation environment has to be capable of generating and removing new instances of nodes during simulation runtime. Moreover, the mobility model has to support this feature in order to add the nodes in a favorable moment during the simulation. Further, the statistical characteristics of the mobility model should not be significantly changed by the addition or substitution of nodes during runtime. In the best case the characteristics are not changed at all.

But only changing the node movement while leaving the channel model unchanged does not lead to valid and reasonable results. Moreover, the use of a road-based mobility model or even a microscopic traffic model in combination with a simple channel model, such as the Free-Space or Two-Ray Ground model [14], leads to misleading simulation results. Hence, the channel model has to be adapted in addition to the node mobility, to model the characteristics of a city environment to its full extend. Without the adapted channel model the use of city maps as a basis for node movement can lead to an improved node connectivity, therefore, modeling a too optimistic case compared to reality (see Sec. 5).

3. NODE EXTERNAL MOBILITY MODELING

In the current source tree of the INET-Framework (version 20061020) node mobility is realized by a mobility module which is part of the MANET-node's compound module. Hence, each node manages its own mobility and generates events to update the node's position. However, if mobility needs to be analyzed globally for the whole scenario, the existing modeling approach is not very beneficial, since each node module would have to be polled individually. In addition, substituting, removing or adding of nodes during simulation time, without altering mobility model characteristics, are not feasible with the existing realization. To overcome these drawbacks we came up with the node external mobility modeling approach, which is introduced in the next section.

3.1 How to Model Mobility Node Externally

The main idea is to move the mobility modeling from inside the nodes to a single module which sits beside the ChannelControl. This new module, called *ExternalMobility*, manages the node mobility for *all* nodes and the deletion and generation of nodes during simulation time.

Listing 1: The ExternalMobility.ned file

```
simple ExternalMobility
    parameters:
        numberOfNodes: numeric const,
        nodeType: string,
        replaceNodesAtBorder: bool,
        nodeLogo: string,
        updateInterval: numeric const,
        speed: numeric,
        waitTime: numeric;
endsimple
```

The base class for realizing an external mobility module is defined by three files: `ExternalMobility.ned`, `ExternalMobility.h`, and `ExternalMobility.cc`. The module definition is detailed in List. 1. The module has six parameters which configure the mobility model. The parameter `numberOfNodes` specifies the number of nodes using the node type given by `nodeType` the model shall generate. If the model shall replace nodes, e.g. at the border of the simulation area, the parameter `replaceNodesAtBorder` has to be set to "true". The node positions are updated constantly using the interval given by `updateInterval`. The speed of the nodes and a potential waiting time are given by the parameters `speed` and `waitTime`.

The C++ class implementation of the module manages the nodes, the positioning, and the interaction with the ChannelControl module. At the beginning of the simulation the method `initializeNodes()` generates the nodes used in the scenario. All nodes are registered at the ChannelControl and the current position is published on the respective NotificationBoard. During simulation time new nodes can be generated (`generateNode()`) or removed (`removeNode()`) from the simulation. Existing events from a removed node are deleted from the event queue. Every new node is registered at the ChannelControl while nodes to be removed are deregistered. Hence, the existing ChannelControl had to be altered to be able to handle the new functionalities and keep the neighbor lists up-to-date.

During the simulation the ExternalMobility "wakes up" by a self-message once every `updateInterval` to update the positions of *all* nodes currently active in the simulation. The `updatePositions()` method calculates the latest node positions and publishes them both to the ChannelControl and the NotificationBoard of the respective node. Therefore, the previously designed node concepts existing for OMNeT++ and the INET-Framework can still be used with the new modeling approach. Simply the node internal mobility model needs to be removed.

$$N_{orig} = t_{sim} \cdot t_{mobint} \cdot N_{nodes} \quad (1)$$

$$N_{new} = t_{sim} \cdot t_{mobint} \quad (2)$$

Besides the possibility to add and remove nodes during the simulation the main advantage of the external mobility modeling is the reduced number of events in the event queue. The conventional mobility model approach used in the INET-Framework generates events for each node. Hence, the number of total events depends on the number of nodes

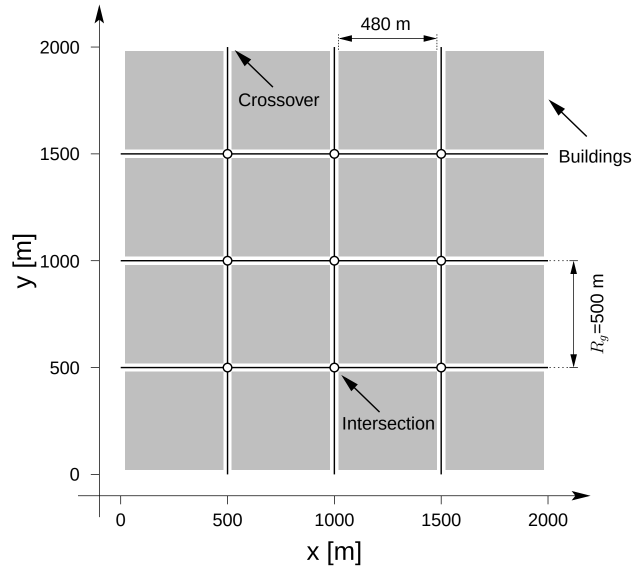


Figure 1: The Manhattan Grid Mobility Scenario

in the scenario (see Eqn. 1). Our new modeling approach generates events independently of the number of active nodes, since the position of all nodes are updates simultaneously. Thus, the number of events are reduced significantly (see Eqn. 2).

In general the external mobility model uses three methods to handle mobility event: `getStartPosition()`, `updatePositions()`, and `movementIncrement()`. The initial placement of the nodes on the playground is done by `getStartPosition()`. Depending on the model characteristics, the current node position, and the node speed the method `movementIncrement()` determines the distance each node moves during one `updateInterval`. As written above, the method `updatePositions()` is continuously called to update the node positions.

3.2 The Manhattan Grid Mobility Model

To demonstrate the functionality of our external mobility modeling concept and to confirm the need for a more sophisticated channel modeling in combination with road mobility models we designed a realistic yet simple street mobility model. It is called Manhattan Grid Mobility Model (MGMM) and its playground layout is depicted in Fig. 1. The mobility model is somewhat similar to the City Section Mobility model presented in [4]. A squared playground is equally divided both horizontally and vertically into a grid of roads, in our case a road is placed every 500 m. Hence, the scenario contains six roads, nine intersections, and twelve crossover points at the border. This scenario size can be seen as the optimal tradeoff between size and simulation performance.

All nodes are handled equally by the model. Each node is placed on the roads randomly at the beginning of the simulation or the beginning of the node lifetime. In a second step the direction of movement is chosen depending on the possible road directions of the node's starting position. Further, the model determines the movement increment $d_{inc} = \frac{S_{node}}{t_{ui}}$, using the node's speed and the update interval of the model. The node's position and the selected movement direction determine the distance to the next intersection or crossover. As soon as a node reaches one of the intersections its position is corrected to remove roundoff errors and the new direction is randomly chosen. If a node reaches a crossover two events are possible. In the regular case (`replaceNodesAtBorder` is set to *false*) the node leaves the scenario and re-enters at a randomly chosen crossover point. If `replaceNodesAtBorder` is set to *true* each node arriving at a crossover point leaves the scenario for good, its `finish()` method is called and the module is removed from the simulation. However, each removed node is replaced by a newly generated node, which enters the scenario at a randomly chosen crossover point. Hence, the node density of the scenario stays the same even if nodes are replaced constantly.

We could have integrated a microscopic trafic model like the ones presented in [10, 12, 17], however, we decided to use a more simple approach to reduce the processing requirements for the support models.

4. CHANNEL MODELING

Up to the most recent release, the INET-Framework implements the Free-Space Path Loss Model (FSPLM) for the computation of the attenuation of the emitted radio signal. Furthermore, the FSPLM is used to calculate the interference that simultaneous distant transmissions cause at a receiver. Combining the transmission power at the sender, attenuation, interference, and the thermal noise results in the Signal-to-Interference-and-Noise-Ratio (SINR), which is in turn used to compute the Bit Error Rate (BER). Evaluation of the BER finally decides whether a transmitted packet is received successfully or not.

Measurements have shown that in real-world scenarios containing a number of radio obstacles (such as arbitrarily-shaped buildings) and moving communication partners, radio signals are influenced by the following (most influential) effects:

- free-space path loss: decay of received signal power due to the distance between sender and receiver
- shadowing: obstruction of line-of-sight (direct path) by obstacles
- (partial) reflection/absorption: at obstacles' surfaces
- diffraction: re-emission of (interfering) radio waves at the edges of very small objects
- fading: constructive or destructive interference caused by multipath propagation, depending on path lengths
- Doppler shift/spread: frequency shift of signal, interference of differently shifted multipath signals

Unfortunately, the FSPLM models only the decay of signal power over distance. It is therefore well suited for scenarios that involve a flat and open playground, but is not useful in scenarios that set in urban environments. Hence, any simulator using a road-based mobility model needs to update the channel model. The distribution of nodes on roads only leads to an artificial increase in node density in a scenario. Depending on the gap between roads and the radio-range this increase in density varies (see Fig. 3 and 4).

For these purposes, a number of channel models have been proposed and discussed [16], among them statistical models based on actual measurements that introduce correction

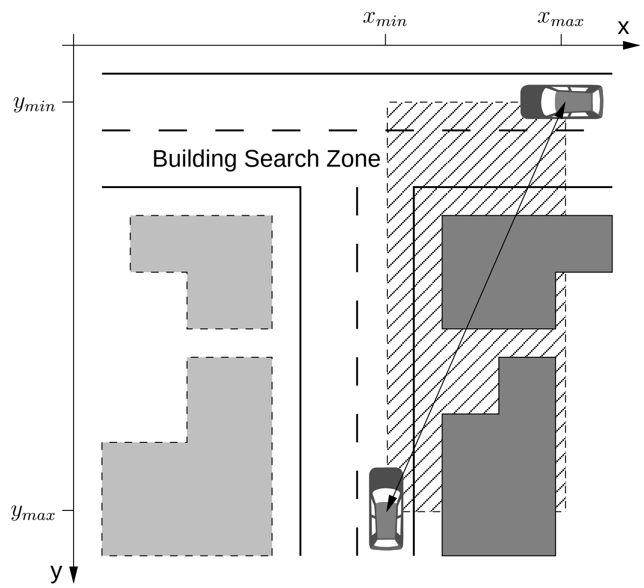


Figure 2: Building Search Zone for the BSP-Algorithm

factors to incorporate some of the effects discussed above. Generally, statistical channel models are computationally inexpensive but only applicable to a limited set of environments (indoor, terrain, city, etc.) and parameters (various frequency ranges). Another more holistic approach is ray-tracing, using optical geometry to model wave propagation on the basis of the geometry of the environment. While this technique is generally applicable and yields very good results in terms of precision, it comes at the cost of computational power, especially in very complex scenarios.

4.1 Geometry

In our model, we have decided to go with an approach that uses environment geometry as the input for a statistical channel model.

In the first step, the radio environment is modeled. Using 2D geometry for simplification, obstacles such as buildings etc., are modeled by a polygonal baseline describing the boundaries of the obstacle. The baselines are stored in a recursive BSP tree [1], enabling an efficient retrieval with the complexity $\mathcal{O}(n) = \log n$.

During a simulation run, the positions of the sender and receiver form the bounding rectangle of the Line-of-Sight (LOS) path (see Fig. 2). This bounding rectangle is used by the BSP algorithm to determine relevant buildings that might obstruct the LOS. In the next step, all faces of the obstacle are checked for intersection with the LOS path. Finally, the intersection points are evaluated and the distances travelled in both free-space d_f and obstacles d_o are computed. As the intersection checking and distance computing is computationally expensive, pre-selection of potentially intersecting objects has proven to greatly reduce simulation time.

Accompanying the MGMM described above, the areas enclosed by the streets are assumed to be quadratic buildings with an edge length of 480 m (see Fig. 1).

4.2 Path loss calculation

The distances d_f and d_o are used in conjunction with a double-regression path loss model, called Dual-Slope Model, where the distance d_f denotes the breakpoint from the sender:

$$L_0 = -20 \log_{10} \frac{\lambda}{4\pi} \tag{3}$$

$$L_p = L_0 + 10 \cdot \begin{cases} \alpha_f \log_{10} d & d \leq d_f \\ \alpha_f \log_{10} d_f + \alpha_o \log_{10} \frac{d}{d_f} & d_f < d \end{cases} \tag{4}$$

L_0 denotes the reference path loss for the wavelength λ at a distance of one meter. The path loss exponents α_f and α_o are also wavelength dependent and have been set to $\alpha_f = 18$ dB/decade and $\alpha_o = 61$ dB/decade [5].

4.3 OMNeT++ Integration

To integrate the extended mobility into the INET-Framework, the `AbstractRadio` base class needed to be modified to pass the coordinates of the sender and the receiver to the used `IReceptionModel`'s method `calculateReceivedPower()`. For backward compatibility with existing reception models, a virtual method was introduced that, if not overloaded, wraps the distance calculation from coordinates and calls the former `calculateReceivedPower()` method. Channel models based on coordinates simply overload this method.

This way, a variety of channel models based on either the distance between sender and receiver or on their coordinates can easily and quickly be implemented without further modifications to the INET-Framework.

5. EVALUATION OF THE SIMULATION MODELS

In the following section we present an evaluation of the models, show their capabilities and limitations. For the comparison we use the well-known and widely used Random Waypoint Model (RWM) presented in [9]. We used a playground of 2000×2000 m^2 and various node densities for our evaluations. The Signal Attenuation Threshold (SAT) was set to -110 dBm and the Signal Reception Threshold (SRT) was set to -85 dBm for a radio-range of about 250 m and to -77 dBm for a radio-range of about 100 m. We used the OMNeT++ version 3.3 and the version 20061020 of the INET-Framework. Both can be found at [20].

The RWM is not very well suited for VANET scenarios, however, in many publications this model has been used and its characteristics are very well known. Thus, we decided to compare our concepts against this model rather than a similar road-based mobility model, which is not well known in the community. Since we're currently integrating a microscopic traffic model, the comparison with more suited models is part of our future work.

5.1 Manhattan Grid Mobility Model

An important characteristic of a mobility model is the node distribution over the playground. Since the MGMM limits the distribution to distinct roads only, the node distribution is a promising measure to compare the model to a well-known model. In a model without placement limitations, like the RWM, an evenly distribution over the full playground is desired. In our MGMM this is only true for the roads, hence, the "area" where nodes can be placed by

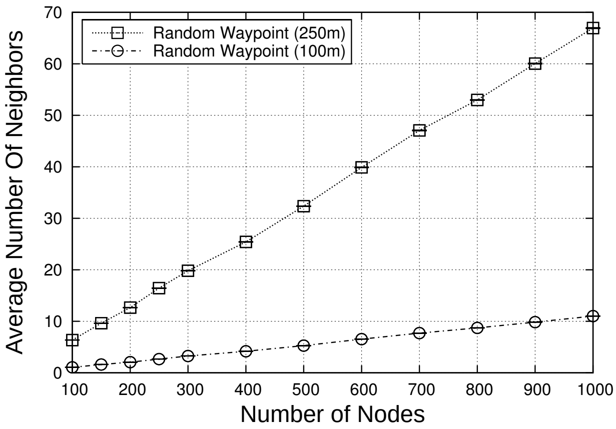


Figure 3: N_n for the Random Waypoint Model

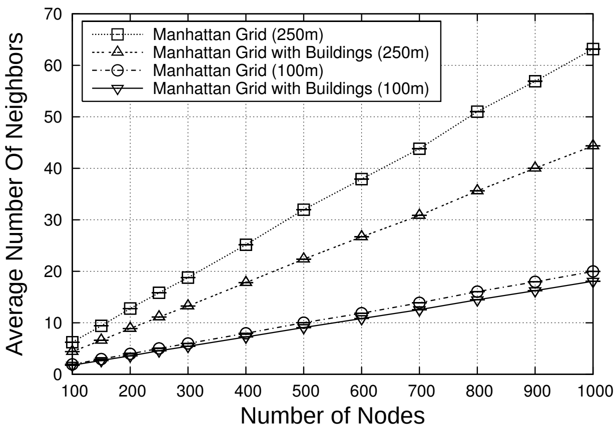


Figure 4: N_n for the Manhattan Grid Model

the model is much more limited. This should result in a considerably higher number of neighbors.

We determined the number of neighbors (N_n), which is the number of nodes within the radio-range of the respective node, for both models. The results for the RWM can be seen in Fig. 3. Two different radio-ranges have been evaluated. As expected the results prove that the smaller the radio-range the lower is N_n. This is also the case for the MGMM (see plots for the MGMM without buildings in Fig. 4). Comparing the results brings up a crucial characteristic of the new model. For shorter ranges the MGMM produces a higher N_n than the RWM, however, for the larger range it shows a slightly lower N_n. The reason for this is that for lower ranges the limited movement area in the MGMM leads to a slightly higher possibility that two nodes are in range than it would be the case for free movement. For the longer ranges the limited movement area is pretty much fully compensated, however, the RWM concentrates nodes more at the center of the playground [3], while the MGMM lets nodes move all the way to the border of the scenario. This effect leads to a more balanced node distribution for the MGMM leading to the slightly decreased N_n.

The results for the MGMM accounting for obstacles can not directly be compared to the other two models, since it is more elaborate and has a slightly different modeling philosophy. However, the results show that taking into account obstacles reduces the connectivity in a VANET significantly and can not be neglected.

5.2 Dual-Slope Channel Model Considering Buildings

Up to now, we have assumed that nodes travelling on different roads can communicate freely, as long as they are within radio-range. Taking the channel characteristics of urban radio propagation into account, it is obvious that buildings placed in the spaces between roads obstruct the LOS path between vehicles travelling on different roads, effectively limiting both the radio-range as well as the interference-range of a transmission significantly.

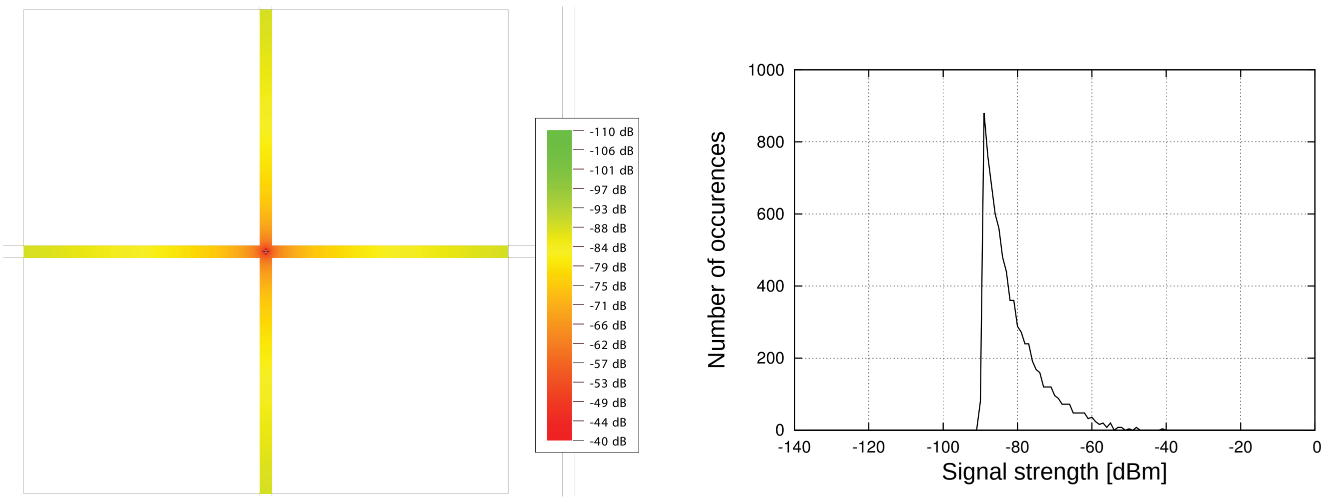
In Fig. 5a, the signal strength along roads has been computed for the situation of a sender positioned on the center of an intersection. In this example, all receivers on any road have an obstructed LOS to the sender. If the sender moves from the intersection on one of the roads (see Fig. 6a), the situation changes dramatically and the signal strength immediately reflects the influence of obstruction by a building: only nodes travelling on the horizontal road have LOS whereas nodes travelling on the vertical road receive a strongly attenuated signal, except for the area very close to the intersection.

The effect can also be seen in Fig. 4: while the number of neighbors in the MGMM is similar to the RWM, taking buildings into account leads to a considerably decreased number of neighbors, because communication is limited to nodes travelling on the same road, nodes travelling on other roads crossing an intersection, and nodes travelling on other roads with both sender and receiver close to an intersection.

As the radio-range is decreased, the impact of obstruction weakens, too. We have already discussed above that smaller radio-ranges lead to a lower number of reachable neighboring nodes. Thus, the length of the road section on which only nodes travelling on the same road are within each others radio-range increases with decreasing radio-range. For these nodes, obstruction by obstacles can be neglected. Therefore, with decreasing radio-ranges the proportion of the length of road section for which obstruction can be neglected compared to the length of those sections for which obstruction needs to be considered, increases. This effect can be seen in Fig. 4 when comparing the influence of obstruction in the upper curves (250 m range) with the lower curves (100 m range).

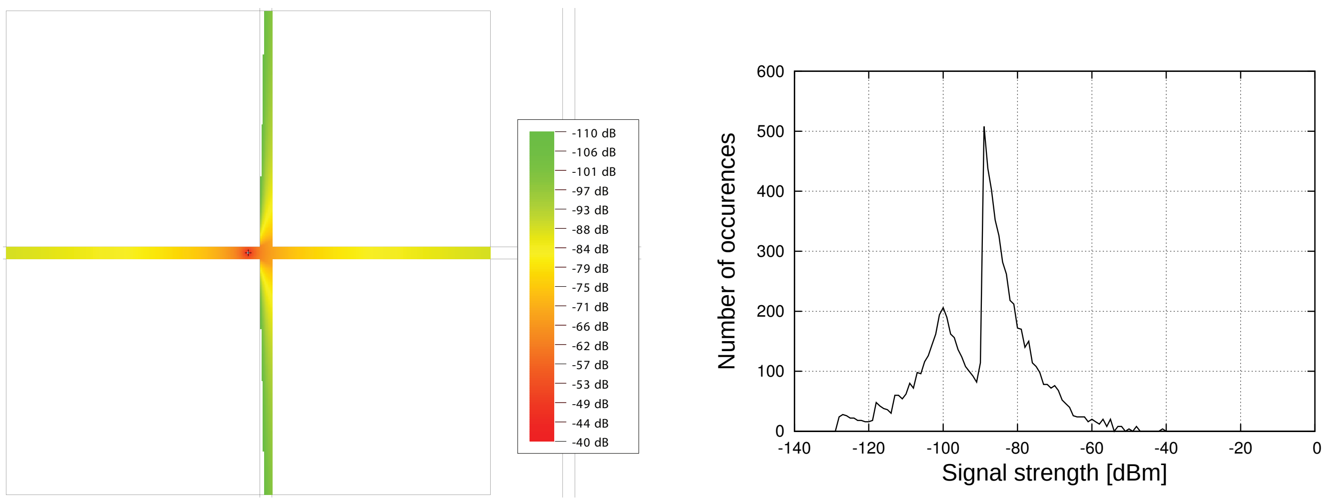
Although signal strengths below -85 dBm cannot be successfully received, they may sum up and interfere with other ongoing transmissions. Especially in the case where a node is positioned close to an intersection, one can see from the histogram that a significant amount of potentially interfering signal is generated in the crossing street (see Fig. 6b).

The SAT which determines the smallest signal strength still being considered in the interference calculations by the simulator, is set to -110 dBm. In the conventional models which do not consider buildings this SAT value amounts to an interference distance of about 4 km. Hence, in a scenario with a playground of $2 \times 2\ \text{km}^2$ all nodes are within the interference range. This, however, is not corresponding to reality. Thus, the incorporation of obstacles makes the interference range calculations also more realistic. The results attained with the Dual-Slope model are given in Fig. 7. The results show that only about 20 to 25% of all nodes remain within the interference range.



(a) Signal strength distribution at intersection (b) Signal strength histogram at intersection

Figure 5: Different power distributions using the Dual-Slope channel model (at intersection)



(a) Signal strength distribution approaching intersection (b) Signal strength histogram approaching intersection

Figure 6: Different power distributions using the Dual-Slope channel model (approaching intersection)

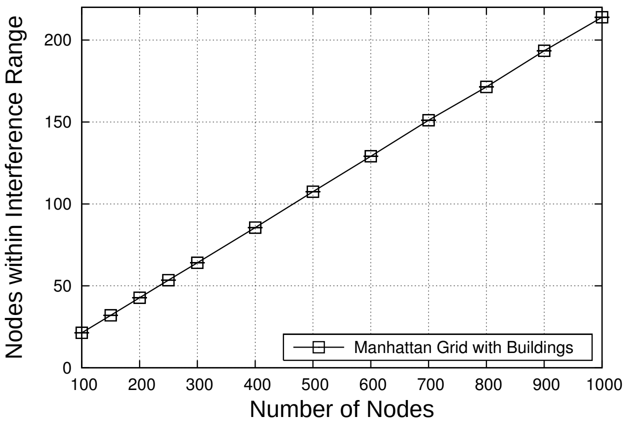


Figure 7: Node-interference density for the Manhattan Grid Building model

6. RELATED WORK

In the following section we give an overview on the related work relevant for this paper. The work is based on the OMNeT++ simulation framework which has been introduced in [21] and can be freely downloaded at [20].

Many different mobility models exist in the literature. Defining these models started with the rise of wireless and especially MANET research. On of the first mobility models which is probably one of the most applied models, the RWM, has been introduced in [9] for the first time. An overview on the multiple models is given in [4].

With the increasing research activities in the area of VNs, new approaches for mobility modeling have been developed. The main goal of these developments is the design of realistic node movement on roads. An approach based on algorithms has been proposed by Jardosh et al. in [8]. The authors use the concept of Voronoi Graphs to define paths in between buildings. In [10] an open-source simulation framework for realistic road mobility, based on a microscopic traffic model developed and described by Krauß in [11], has been presented. The system allows to model vehicle movement using digital maps. Similar concepts have been introduced in [15, 6, 19] and [17]. All of these models concentrate on the mobility of the nodes only, while the channel characteristics of the environment remain untouched. As we showed in our paper, this simulation approach leads to very optimistic connectivity characteristics for the city scenario. Since most of these new mobility modeling concepts run outside of the network simulator a coupling concept needs to be found, allowing for a reliable and realistic exchange of position information. Several feasible coupling methods, their advantages and problems have been detailed in [7].

A very sophisticated modeling approach for VNs has been presented in [12]. The authors present a coupling between the complex traffic modeling suite VISSIM, the network simulator ns-2, and the application modeled using Matlab, where two simulation machines are connected by an Ethernet link. In contrast to this approach, our concept can run simulations on one computer only, since all models are integrated into the OMNeT++ simulator, and it consideres buildings in the channel modeling.

Our model uses the BSP algorithm to organize the obstacle database in a search tree. The concept of Binary Space Partitioning has been suggested by Agarwal et al. in [1].

The research in the area of channel modeling is manifold. Many different approaches exist in the literature, varying in complexity and accuracy. Excellent overviews can be found in the surveys [4, 16] as well as the Technical Report [2]. In those publications most of the propagation effects and many of the widely used models are described. The parameters we used for the Dual-Slope model in this paper can be found in [5]. Modeling the channel very realistically is feasible [13], however, the used technology of optical ray-tracing requires very high processing capabilities, making a near realtime simulation of larger network scenarios impossible at the moment.

7. CONCLUSION

In this paper, we have outlined the specific simulation requirements for VANET scenarios in OMNeT++. We have presented both a mobility and a channel model, incorporating the specific characteristics of a city environment like roads and buildings, and how they can be integrated in the simulation environment. Furthermore, we have shown their validity on the basis of representative simulations. Also, beside an advanced channel model, we have created the necessary basis for the inclusion of other components involved in the radio propagation process such as specific profiles for smart-antennas.

Future work will include interfacing with a microscopic traffic simulator (as presented in [19]). To improve the accuracy of the channel model concepts based on ray-tracing, such as [13], shall be integrated as far as the complexity of the model is still manageable.

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