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CosMos – Communication Scenario and Mobility Scenario Generator for Mobile Ad-hoc Networks

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Abstract

One of the most important components of mobile ad-hoc network simulations is the mobility model, since it defines the movement of mobile nodes and thus indirectly the network topology. The network topology at a given time in turn influences the performance of an ad-hoc network, for example the performance of routing algorithms changes with the mobility model.

In this paper we introduce a communication and mobility scenario generator for mobile multi-hop ad-hoc networks. The goal is to aid researchers in the design of 'realistic' simulation scenarios which emulate real cities. Our approach combines a wide variety of well understood random mobility models with a graph-based zone model, where each zone has its own mobility model and parameters. The combination of directed, weighted graphs where the weights correspond to the flow of mobile nodes between neighboring zones and zones with different mobility models, allows the researcher design more realistic simulation scenarios.

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1 Introduction

A mobile ad-hoc network is created by a collection of nodes which communicate over radio. In contrast to a wireless local area network (WLAN), where at least one access point regulates the access of the nodes, an ad-hoc network does not need any such infrastructure. Therefore, ad-hoc networks offer immense flexibility. Additionally, it is supposed that ad-hoc networks are inherently adaptive and auto-configured. These properties of ad-hoc networks have increased the interest in them in recent years, also for real world scenarios.

The vast research in mobile ad-hoc networks, consisting in development and evaluation of applications and protocols, has been done by using simulation tools. Simulation tools provide repeatable scenarios and isolation of parameters. The latter property allows studying one parameter by fixing others.

Since there are several parameters which have to be selected properly for simulation runs to be able to gain proper results and interpret them. Beside other parameters like media access control and routing algorithm, there are two parameters which have a special role. These are the mobility and communication models.

The communication model determines the application character which is run on top of the network. The mobility model characterizes the movement behavior of the mobile nodes during the simulation time and is therefore also responsible for the network topology. It is obvious that the mobility and communication models could be considered independently from each other. However, some applications inherently define both of them. For example, the scenario of people in an exhibition walking and talking to each other defines the mobility characteristic as well as the communication characteristic. The same assumptions will probably not work to model an entire city with several places and streets on which people move differently.

In this paper we introduce a communication and mobility scenario generator for mobile multi-hop ad-hoc networks (CosMos). The aim of CosMos is to provide the research community with more realistic mobility patterns for wireless and ad-hoc network simulations. Our contribution consists of:

- A simulation world concept based on directed and weighted graphs.
  - A zone characterizes a certain geographical area and has several properties including mobility model, population, and geometric shape. Mobile nodes move on a zone according to its properties.
  - There is a particular property of a zone called the neighborhood property which is set by the user and defines the neighbors of the zone. Furthermore, the exit probability of a zone specifies the rate with which mobile nodes move to neighboring zones.
  - The zones together with the neighborhood properties build a graph, where zones are the nodes, and the neighborhood properties define weighted and directed edges and thus define the flow of mobile nodes between neighboring zones.

- A tool which supports the design of complex simulation scenarios
  - CosMos has a graphical user interface (GUI) that supports the user in the design of simulation scenarios. The user can define and edit zones on the simulation area.
  - A set of mobility models is provided from which the user can select. Furthermore, the interface of the mobility model is open and hence allows the simple extension of the available mobility models.
  - A set of predefined communication models is provided. The focus is set on audio communication, i.e. duplex-traffic.
  - The generated mobility and communication patterns are designed to be used with the ns-2 network simulator, but can be easily extended to support other simulation tools.
  - CosMos can generate input files for nam on the fly, i.e. before simulation runs. This enables the researcher to check the simulation scenario before starting long simulations.

The remainder of this paper is as follows. In Section 2, we review some proposals from literature. Subsequently in Section 3, we introduce CosMos. The paper closes with some conclusions.

2 Related Work

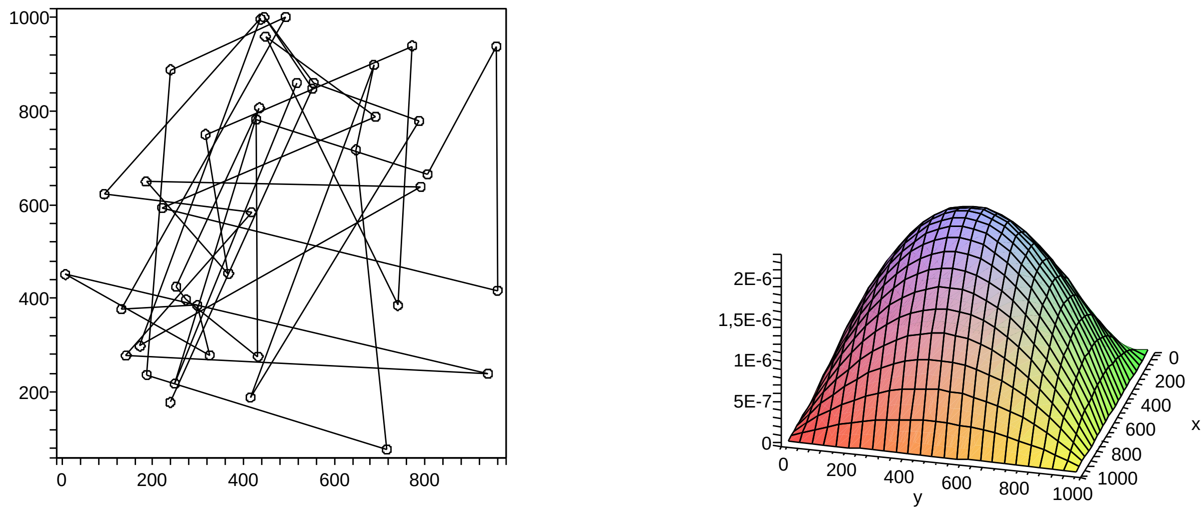
In this section we describe common used random mobility models as well as their recently published refinements. Beside the random mobility models, we also discuss one mobility model based on social networks. At the end, we present our analysis on the mobility traces of the Stanford University and discuss their contributions for simulation of ad-hoc networks.

There are many random mobility models proposed in the literature. The models can be generally distinguished in two classes: i) entity mobility models, and ii) group mobility models. Detailed descriptions of common used random mobility models and their impacts on ad-hoc network simulation is given in [1, 2, 3, 4, 5].

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 $[\varphi_{\min} : \varphi_{\max}]$ and $[v_{\min} : v_{\max}]$, 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. The pause time is fix for all nodes. A



(a) 2D movement pattern

(b) Node distribution

Figure 1: Random Waypoint

disadvantage of this model is the concentration of nodes in the center of the simulation area (see Figure 1(b)). 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 is that these models are memoryless, i.e. a node does not consider the visited locations when selecting the next one.

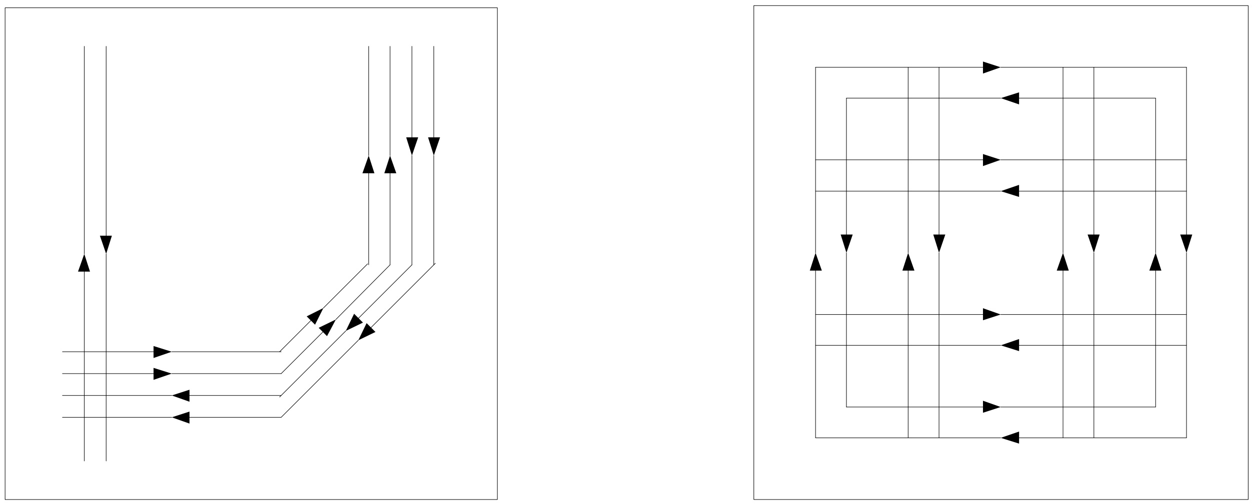
The Gauss-Markov model prevents the problem of sharp direction changes by taking the most recent moves into the calculation of the next destination. Therefore, the resulting movement pattern is more smooth.

Beside these 'plain area' models, there are also some models which try to map the characteristics of car movements on streets (see Figure 2). In the Freeway model, there is at least one lane in each direction of a street (see Figure 2(a)). 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 (see Figure 2(b)). 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) Freeway (b) Manhattan

Figure 2: Mobility models for streets

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 assumption does not hold in the real world where movement paths are restricted on certain ways or streets.

In [6] a refinement of random mobility models by integrating obstacles is proposed. The obstacles represent buildings. Upon the definition of buildings, paths between the buildings are calculated by using Voronoi diagrams. The mobile nodes are randomly distributed on the paths and the destinations of the nodes are selected randomly among the buildings. The nodes move afterwards on shortest 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.

2.4 Mobility based on social networks

The group mobility models discussed in Section 2.2 calculate the movements of entities in a group randomly. The social relationships among humans are not considered.

In [7] a mobility model based on social networks is presented. The model is divided in two-levels. At the first level, artificial social relationships among mobile entities are defined, and at the second level the social organization is mapped onto a topographical space. The artificial social relationship is defined as a matrix $M = \begin{pmatrix} 1 & \cdot & \cdot \\ . & \ddots & . \\ \cdot & \cdot & 1 \end{pmatrix}$ in which the entry $m_{i,j} \in [0, 1]$ represents the interaction between the individuals i and j, 0 stands for no interaction and 1 for strong interaction. The diagonal elements $m_{i,i}$ represent the interaction of an entities with themselves and are set to 1.

Entities belong either to a group or stay alone. The movement of an entity which belongs to a group is given by the group movement and its own movement within the group. Entities which do not belong to a group move merely by themselves. The group mobility as well as the entity mobility are however defined by random mobility models.

2.5 SUMATRA

SUMATRA [8] is the abbreviation for Stanford University Mobile Activity Traces. It is a trace generator developed at the Stanford University. The main advantage of SUMATRA is according to the publishers, that it is validated against real data.

The Stanford University has published four traces which model connection oriented traffic. Two of them are based on simple rectangle layout (SULAWESI, S.U. Local Area Wireless Environment Signaling Information) and the other two are based on the San Francisco Bay Area (BALI, Bay Area Location Information), see Figure 4. The traces are downloadable from [8].

The goal of publishing these four traces was to give the wireless research community a common benchmark. Since the traces contain call as well as mobility information of mobile users; results of experiments made with these traces are comparable and hence give researchers a better way to compare their results. The traces contain the following information for a call and move event:

- Call: ID's of the caller and called mobile user, the zone ID's in which they are being, the time when the connection is started, and finally the duration of the call.

- Move: ID of the mobile user, the current zone ID, the zone ID in which the user moves as next, and the time of the movement.

Unfortunately, the SUMATRA traces have some disadvantages and thus it is difficult to use them for ad-hoc network simulations. The main problem is that it is not specified how a user travels from one zone to another. The velocity of the user is unknown, there is only a global velocity of 15 mph defined. Therefore, you cannot figure out how long a travel lasts, which positions the user visits, and when it finally reaches the final position.

Despite the deficiencies, it is worth to consider it. As next we focus on the BALI trace, since the others were out of our interest. The mobility and call characteristic of the BALI

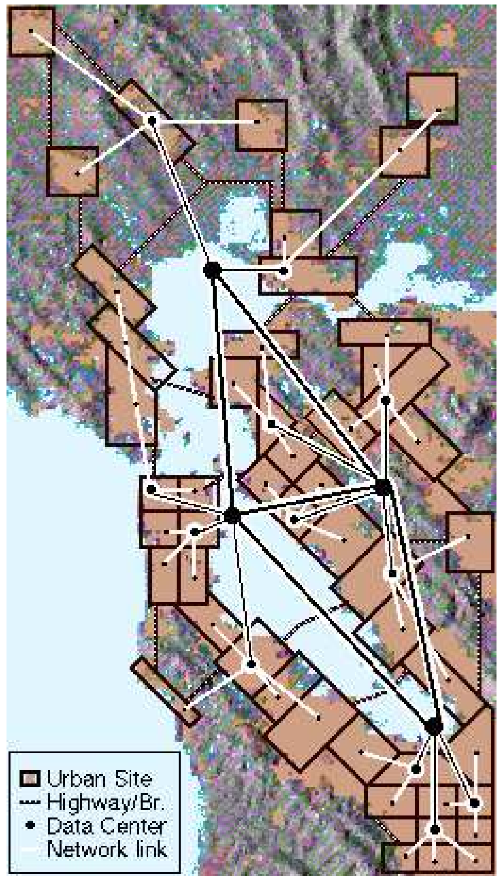
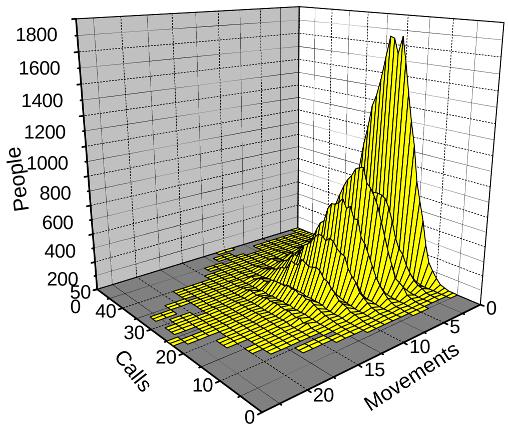


Figure 3: Zone layout of the BALI trace

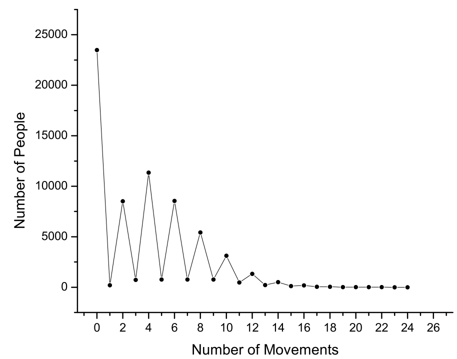
trace is depicted in Figure 4. In Figure 4(a) a histogram of the number of people with a certain number of movements and calls is depicted. The graph has some interesting properties. The calls show a typical Gauss distribution and the movements show an exponential distribution, i.e. there are many people with little movements and few people with many movements. Furthermore, there are some clustering regarding the number of movement. This is more clearly depicted in Figure 4(b). The number of people with odd movements are negligible. The vast majority of the people perform an even number of movements. The reason for this could be that the most people in the San Francisco Bay Area are commuters which do the same number of movements from home to work and back.

2.6 Real traces

The best input for simulations would be the ones derived from real traces. However, it is very difficult for the research community to obtain those data. Therefore, there are few studies reported which are based on real data.



(a) Histrogram of movements and calls. The calls show a Gaussian distribution and the movements an Exponential distribution



(b) The number of people as a function of the number of movements. The number of people with odd number of movements is negligible. The reason for that could be the assumption that the most people in the Bay Area are commuters.

Figure 4: Characteristics of the BALI trace

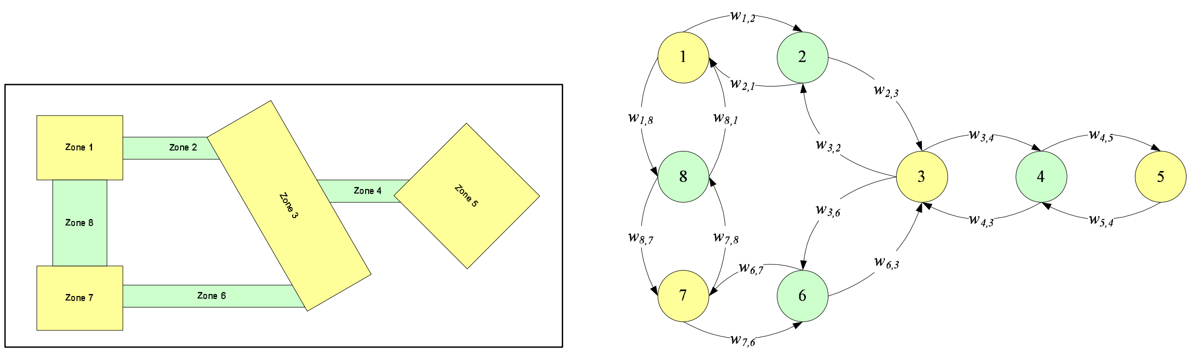
3 CosMos

In this section we introduce the Communication Scenario and Mobility Scenario Generator (CosMos). The goal of CosMos is to aid researchers design more realistic simulation scenarios for wireless and mobile ad-hoc networks.

We start with an example to illustrate our aim in the development of CosMos. A man leaves his home in the morning, walks to his car on the street, drives to the freeway and then travels on the freeway to the city where his workplace is, he leaves the freeway and drives through the city to this workplace. In this scenario the observed man or in abstract the 'mobile node' changes its mobility characteristic several times, i.e. the mobility model and the velocity.

The mobility models discussed so far map some of the characteristics of the real world and hence a part of the described scenario. At the same time, most mobility trace generators restrict the user on the selection of single mobility model. Therefore, it is not easy to design a simulation scenario which is oriented towards a real city.

The aim of CosMos is to fill this gap and it supports the research community with more realistic simulation scenarios. CosMos integrates several mobility models, which can be combined within a common scenario, e.g. some of the mobile nodes can behave according to the Random Waypoint and others to the Manhattan model.



(a) Map view (b) Graph view

Figure 5: Simulation world of CosMos

Zone	Application	Mobility Model
1	City	Random Waypoint
2	Street	Freeway
3	City	Manhattan Model
4	Street	Freeway
5	Mall	Random Point
6	Street	Freeway
7	City	Manhattan
8	Street	Freeway

Figure 6: A possible mobility setting for example from Figure 5

3.1 The World of CosMos

Figure 5 schematically shows the simulation world concept of CosMos. It is composed of a set of zones. Each zone has a set of general properties and depending on the selected mobility model some additional ones. General properties are coordinates on the map and the number of mobile nodes. Some of the properties depending on the mobility model are the minimum and maximum velocity, the pause time, and the number of movements.

There are 8 zones in the specific example of Figure 5(a). The zones 1, 3, 5, and 7 represent an area on which people can walk, e.g. a city center or a mall. The zones 2, 4, 6, and 8 represent roads, e.g. streets or freeways. In Figure 6 a possible setting of mobility models of the zones is shown.

Among zones a neighborhood relationship is defined, which is set explicitly by the user. The simulation world of CosMos builds a directed and weighted graph with zones as nodes and the neighborhood relationship as weighted and directed edges. The graph for the example in Figure 5(a) is depicted in Figure 5(b). The weight of a directed edge is denoted as 'exit probability' and gives the rate with which mobile nodes leave the zone.

3.2 Node Movement

The number of mobile nodes in each zone has to be specified by the user. The mobile nodes of a zone are uniformly distributed on the zone according to the rules of the mobility model. The mobility of a node is distinguished into two parts: i) intra-zone mobility, and ii) inter-zone mobility.

3.2.1 Intra-zone mobility

As mentioned earlier each zone has its own mobility model which is set by the user. The intra-zone mobility is therefore defined by the specific settings for that zone. A node in zone i moves according to these settings. CosMos supports in the current implementation the following mobility models:

- Random Point Model
- Random Waypoint Model
- Freeway Model
- Manhattan Model

3.2.2 Inter-zone mobility

The inter-zone mobility describes how mobile nodes move from a zone to one of its neighbors. A zone i uniformly selects among its population a node, which moves to one of its neighbors. The selection of the next zone j for this mobile node depends on the weight $w_{i,j}$.

Before a mobile node can leave its current zone it has to move to a handover area (see Figure 7). The handover area is defined as the intersection of the current zone i and the next zone j. Since a zone is geometrically modeled as a polygon, the handover area of two zones is given by the intersection of the polygons [9].

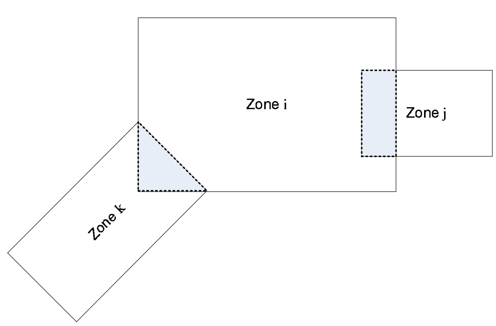


Figure 7: Handover areas of zone i with its neighbors zone j and zone k.

This method of handing over a mobile node from one zone to another zone requires the slightly 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 exactly this location on the handover area. We think, that 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.

The chosen mobile node is deregistered from its current zone i and registered in the new zone j and handed over on its position on the handover area. After that, the mobile node is subject to the settings of the new zone j.

3.2.3 Node distribution

The movement of a mobile node between the zones can be modeled as a Markov-Chain. The state is given by the zone number in which the mobile node is being. The transition matrix M is derived from the exit probabilities of the zones. The state probability for a given step j is given by $p_j = p_0 \cdot M^j$.

Furthermore, the steady state distribution of the nodes, which is independent from the initial distribution, is given by the equation $\pi = \pi \cdot M$. Let $n = n_1 + \cdots + n_k$ be the total number of mobile nodes in the simulation world. Since all nodes behave independently, the average number of nodes n_i in zone i is given by $n_i = n \cdot \pi_i$.

3.2.4 Example

In this section we discuss a simple scenario in two different settings to show some of the characteristics of CosMos.

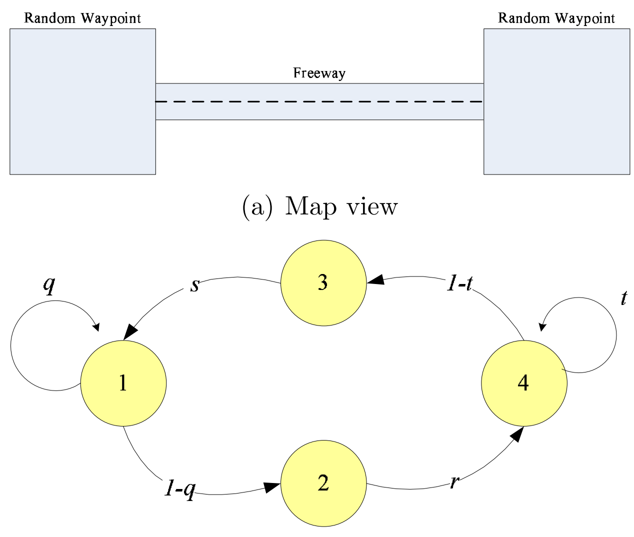
Figure 8 shows an example with three zones where two places are connected by a street. The two places have the size of 500 m $\times$ 500 m and the street has the size of 1000 m $\times$ 100 m. This is to ensure that two nodes on different places cannot communicate directly. The graph of the simulation world is also depicted in the figure. Mobile nodes can move from the left and right place onto the street and vice versa. The exit probabilities are depicted in the graph in Figure 8(b).

The general transition matrix M for this example is given as follows.

$$M = \begin{pmatrix} q & 1-q & 0 & 0 \\ 0 & 0 & 0 & r \\ s & 0 & 0 & 0 \\ 0 & 0 & 1-t & t \end{pmatrix} \qquad q, r, s, t \in [0, 1]$$

It is worth to mention, that the street is modeled as two different nodes in the graph of Figure 8(b), namely nodes 2 and 3.

First setting: The mobility model of the street is the Freeway model with one lane in each direction. The exit probability of the street is set to $r = s = 1$ for each direction, i.e.



(a) Map view

(b) Graph view

Figure 8: Example simulation world consisting of three zones.

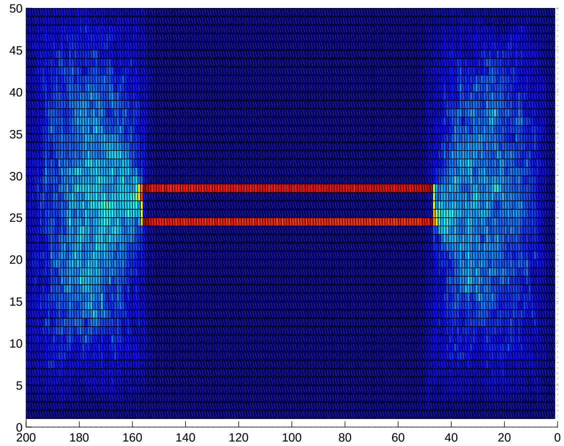
a node on the street drives until the end and moves to the place and is afterward subject to the settings of that place. The exit probability of the places are set 0.7, i.e., $q = t = 0.3$ with probability 0.7 a node will leave its current place to go onto the street and than to the other place.

In Figure 9 the mobility probability distribution for the first setting is depicted. In this scenario the mobility model of both places is set to Random Waypoint. The typical property of the Random Waypoint model, namely the gathering of nodes in the center of a zone is observable. However, the gathering is modified into the vicinity of the handover area. Due to the high exit probability of the zones, the highest probability to meet a node is on the street connecting both places.

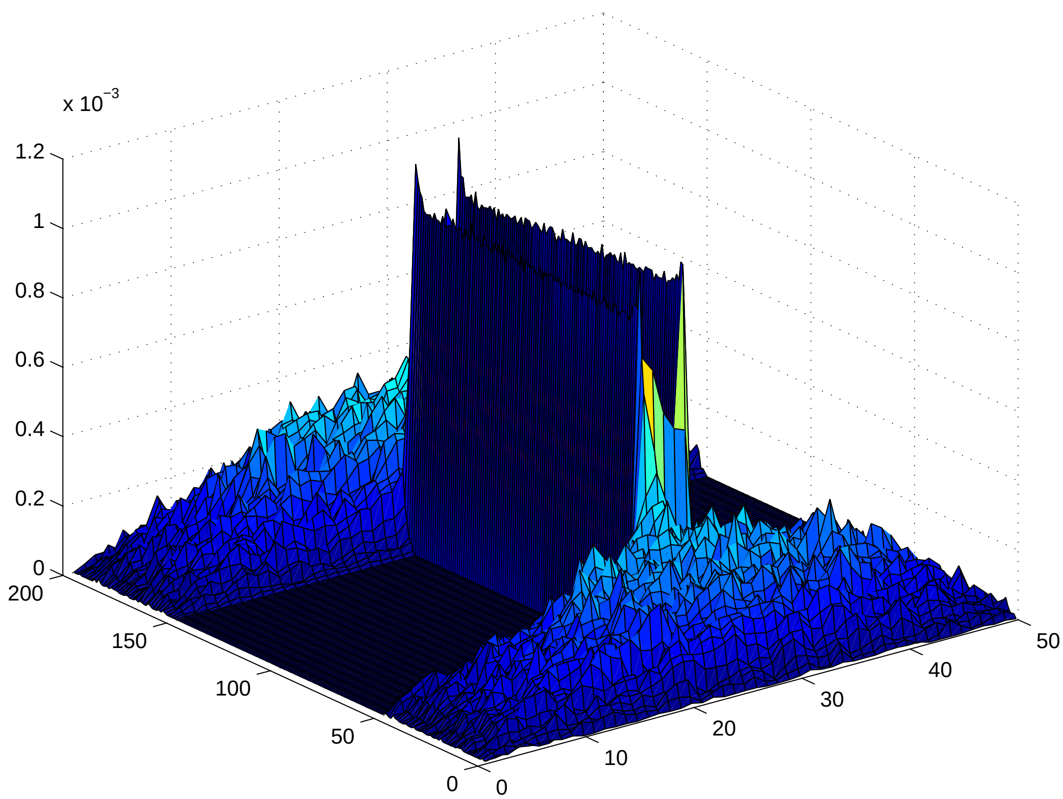
Second setting: In this scenario the mobility model of the left place is changed to the Manhattan model with 2 lanes in horizontal and vertical direction. All other settings are the same as in the first setting. In Figure 10 the mobility probability distribution for the second setting is depicted. The properties of both of the mobility models are observable. In the left place, the movement of the nodes on the streets are depicted with high probabilities. As similar to the first setting, the highest probability to meet a node is on the road connecting both places.

3.3 Communication models

In contrast to the mobility models, the communication model is not a property of the zones, instead it is a general property of the simulation scenario. The user can specify plenty of parameters like the number of connections, the packet size, rate, maximum number of

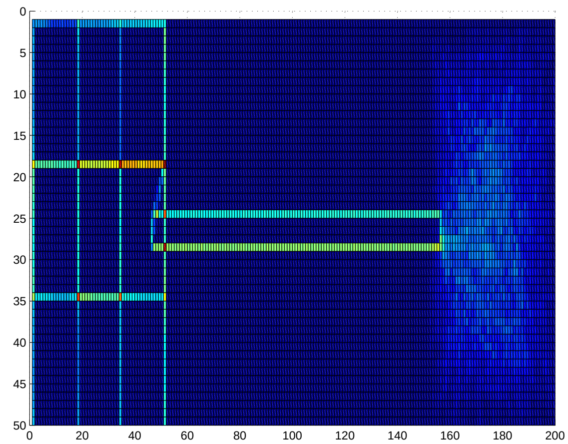


(a)

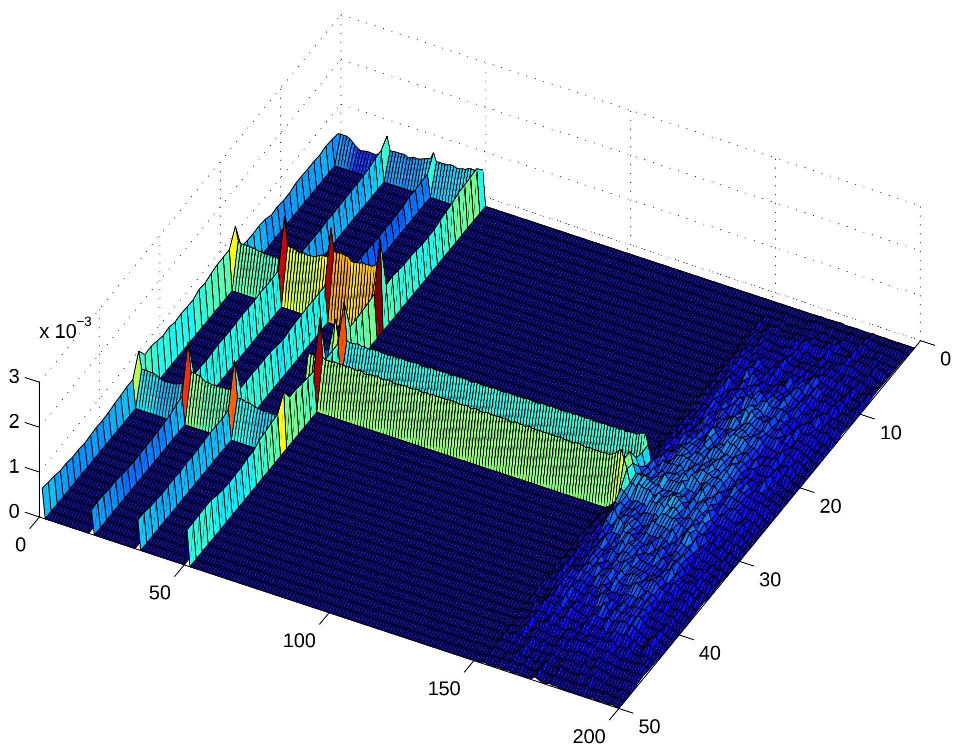


(b)

Figure 9: Two places are connected by a street. The mobility model of both places is set to Random Waypoint.



(a)



(b)

Figure 10: Two places are connected by a street. The mobility model of the left place is set to Manhattan model with 2 lanes in horizontal and vertical direction. The mobility model of the right place is set to Random Waypoint.

packets, etc. Most parameters are derived from ns-2, since our intention was to generate input files for simulations with ns-2.

CosMos supports simplex-connections as well as duplex-connections. In the case of duplex-connections, both nodes are sender and receiver. The source and destination of a connection is selected uniformly among the mobile nodes.

3.4 Implementation

CosMos is implemented in C++ and uses the Qt library for the GUI. In its core, it is a discrete event simulator. The GUI supports the researcher in the design of complex scenarios (see Figure 11). Zones can be edited by mouse operations and the properties are specified within dialogs. Screenshots of some of the dialogs are shown in Figure 12. The description of a simulation world can be saved on disc and later loaded to work on it, which allows the incremental improvement of the design.

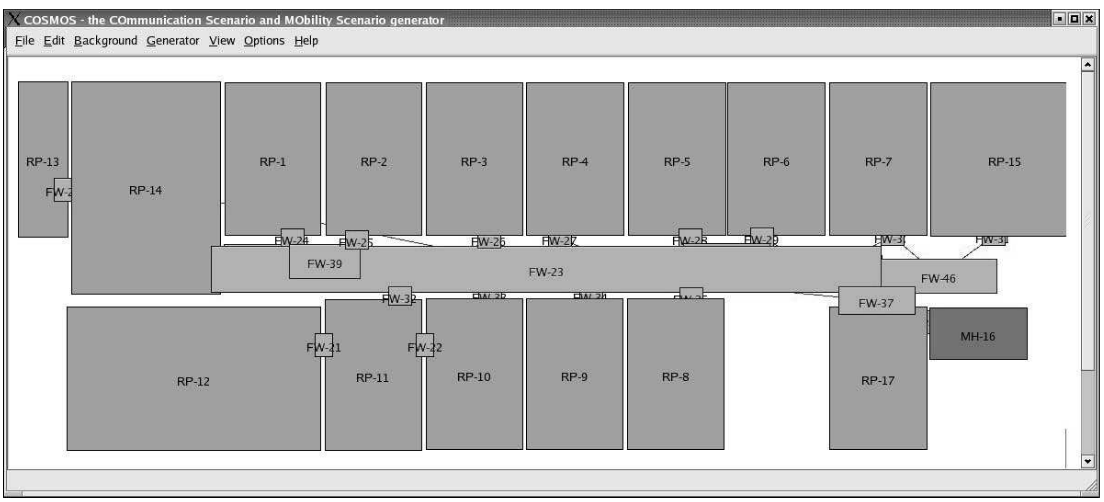
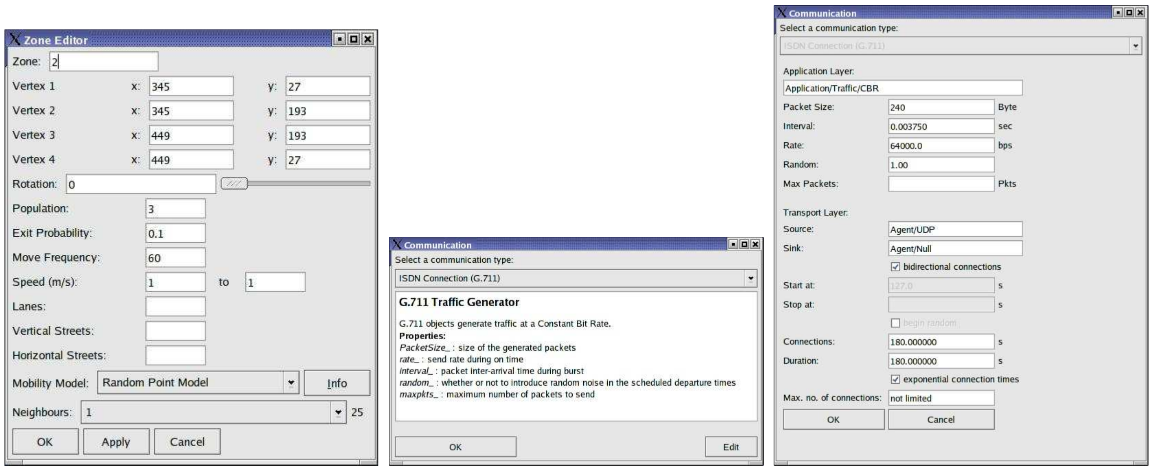


Figure 11: The GUI of CosMos

Some of the more interesting and sophisticated features of CosMos are:

- Zone editing: A zone is geometrically modeled as a polygon and therefore very flexible in its shape. Zones can be positioned with the mouse or by setting the coordinates on its property dialog. The neighborhood relationship can also be set in that dialog.
- Background image: CosMos supports the loading of a background image which for example could be a map of a city. The simulation area can be scaled to the metrics of the background image, which simplifies the positioning of zones.
- Zoom: The whole simulation area can be zoomed in and out. This supports the exact positioning of zones.



(a) Zone editor (b) Traffic selection (c) Traffic editor

Figure 12: CosMos GUI Interfaces

- Visualization: A zone, depending on its mobility model, has a particular color, the neighborhood relationship is visualized by lines, and the abbreviation of the mobility model together with its zone ID is displayed at the center of the zone.

3.5 Simulation tool support

In the current version CosMos generates input files for ns-2 and nam. However, it is quite easy to extend it for the generation of input files for other simulators like GlomoSim.

For ns-2, movement and communication files are produced which can be loaded during simulation runs. CosMos generates the visualization file for nam on the fly and starts nam with the generated file, so that the researcher can check the mobility of the nodes before performing simulations. This feature is especially helpful in the case where complex scenarios are developed.

4 Conclusions

The mobility model is a very important component of mobile ad-hoc network simulations, since it defines the movement of mobile nodes and thus indirectly the network topology. The network topology at a given time in turn has its influence on the performance of an ad-hoc network, e.g. the performance of routing algorithms changes with the mobility model.

In recent years the interest for the deployment of ad-hoc networks for real scenarios grew. Therefore, the research community is forced to improve the understanding by experimenting mobile ad-hoc networks with more realistic simulation scenarios. This demands for realistic mobility models. The vast majority of ad-hoc network research deploys random mobility models, since they are simple, well understood, and most network simulators provide some of them. While random mobility models are adequate for a specific part of the reality, they are not able to model the reality in whole. Beside this, most tools restrict the researcher on only one mobility model.

In this paper we have introduced a new communication and mobility scenario generator for mobile multi-hop ad-hoc networks. The goal was to aid researchers in the design of 'realistic' simulation scenarios which emulate real cities. Our approach combines a wide variety of well understood random mobility models with a graph based zone model, where each zone can have a different mobility model. The combination of directed, weighted graphs, where the weights corresponds to the flow of mobile nodes between neighboring zones, and zones with different mobility models, allows the researcher in the design of more realistic simulation scenarios.

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