Klaus Wehrle,Mesut Gnes, James Gross
(Editors)

Network Simulation Modeling

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1. Modeling Mobility

Andras Berl (University of Passau)

1.1 Introduction

In wireless networks, communication can take place based on an infrastructure (e.g. WLAN access point or GPRS base station) or it can take place in ad-hoc mode, where mobile devices are connected directly to each other and care for the routing by themselves (mobile ad-hoc networks). When such wireless networks are investigated and simulations are performed, it is often necessary to consider the movement of entities within the simulated environment. There are several common examples of scenarios that involve a movement of entities:

– A number of WLAN access points are installed in a building and configured in infrastructure mode. Users are moving within the building and are roaming between the different access points without loosing connectivity.
– Users with cell phones are walking in a city. While moving, the cell phone changes the base stations it is connected to (handover, see Chapter **??**). The user is able to continue a telephone call without interruption.
– Cars (e.g. driving on a highway) use car-to-car communication to pass each other information about congestion or an accident. To do so, a mobile ad-hoc network is set up between cars that are near to each other. Such networks are often called vehicular networks.
– In an emergency situation (e.g. an earthquake or a fire in a big building) the fire brigade, ambulance, and police are setting up a mobile ad-hoc network to clarify further proceedings.

In such scenarios (and many others) the mobility of entities in the network plays an important role when communication has to be established. Protocols (e.g. routing or handover algorithms) need to be optimized with respect to the experienced mobility. Actually, the results of network simulations that include mobility of entities can vary significantly when the mobility patterns of moving entities are changed (see Section 1.4).

Often, it is difficult to gather real movement data (also known as traces, see Section 1.2) of a sufficient number of entities for simulations. To overcome this problem, synthetic mobility models have been developed that are generating simplified virtual movement data for a number of entities. There are several mobility models with different properties. Section 1.2 categorizes mobility model approaches. Section 1.3 presents several approaches of mobility models in detail. Section 1.4 discusses the appropriate selection of mobility models for certain simulation scenarios and gives hints for the selection. Section 1.5 concludes this chapter.

1.2 Categorization of Mobility Models

This section describes different categories of synthetic mobility models. Due to the vast amount of available models and scenarios, the categorization presented in this Section is not exhaustive, there are further categories of mobility models which are not discussed in this section. Furthermore, the categories are not disjunctive to each other. A single mobility model may fit in several of the presented categories. In spite of this incompleteness, the presented categorization helps to get an overview of mobility models and to get an impression of the diversity of available models and simulation scenarios.

1.2.1 Traces and Synthetic Mobility Models

Traces are mobility patterns that are logged from real life situations. Tuduce et al. [7] give an example for the logging of traces. The study monitored 350 WLAN access points spread over 32 buildings for three months. The access points were configured to run in infrastructure mode. MAC addresses of network interface cards identified the users. The access points were polled every minute for user association information. This way, the location of WLAN users was gathered (as long as the users were online) and implicitly also an estimation of the users movements. In another example, Tang et al. [6] traced the mobility of 74 users in a campus network for 12 weeks. Additionally, operators of mobile cellular networks might provide interesting traces of users that are using cell phones.

Synthetic mobility models, which are the main focus of this chapter, are not directly based on the logging of users' movement behavior. Instead, mobility patterns are generated by algorithms that specify virtual behavior of users and predict their movements. These movements of virtual users are usually constrained to a simulation area with limited border lengths. On one hand, synthetic mobility models can be inspired by traces, attempting to model the users' behavior in realistic situations. On the other hand, traces can be used to verify synthetic mobility models by comparison.

1.2.2 Entity and Group Mobility Models

Mobility models can be categorized by the number of entities that are described by a single mobility model.

Entity mobility models consider the movement of a single individual entity, e.g., a human being or an animal. If there are several entities, they are typically considered independently from each other and their movements are predicted independent from each other. Also the number of entities that are existing in the simulation area is not considered in the algorithm that predicts a single entity's movement. Examples of entity mobility models are the Random Walk Model, the Random Waypoint Model, the Random Direction Model, the Gauss-Markov Model, or the Manhattan Model (see Section 1.3).

Group mobility models in contrast, consider a set of individual entities as a group, which is moving as a whole. The movement of entities is related to each other. Usually, there is a group leader or another moving point of orientation. The group entities gather around this orientation point and follow its movements with specified deviations. Group models are often said to be more realistic than entity mobility models. In reality, the movement of human beings is usually not independent from each other. People are walking around in groups or have similar directions (e.g. towards a shopping center). Animals are often moving in herds or swarms. Examples of group mobility models are the Pursue Model, the Column Model, the Nomadic Community Model (see Section 1.3), or the Reference Point Group Model [1].

1.2.3 Human, Animal, and Vehicle Mobility Models

Another categorization of mobility models is based on the nature of the entity that causes the movement. The criteria of this categorization is not the amount of entities, but the behavior of the entities.

Human mobility models are describing the movements of human beings in certain scenarios. Examples for such scenarios are pedestrians in inner cities or employees during work in a building. Examples of human mobility models are the Random Walk Model, or the Random Waypoint Model.

Animal mobility models are analogously based the movement of animals, e.g. in herds or swarms. Examples of animal mobility models are the Random Walk Model, the Pursue Model, or the Nomadic Community Model.

Vehicle mobility models are predicting the movement of vehicles (e.g. cars or tanks). Often the mobility of vehicles is restricted to streets and traffic rules, which imposes particular restrictions on their mobility patterns. Examples of vehicle mobility models are the Freeway Model [1], or the Manhattan Model.

1.2.4 Normal Situation and Special Situation Mobility Models

Mobility models can also be categorized by looking at the character of the situations which they are describing.

Normal situation mobility models are assuming ordinary scenarios without special influences. People are walking in a pedestrian area, working in a building, or driving on streets, for instance. Examples of human mobility models are the Random Walk Model, the Random Waypoint Model, or the Manhattan Model.

Special situation mobility models are modeling unusual situations in which entities show specialized movement behavior. Emergency situations are examples of such special situations, e.g. a fire in a building or an earthquake. Examples of Special Situation Mobility Models are the Pursue Model or the Column Model.

1.2.5 Other Mobility Models

Apart from the presented categorization of mobility models there are further mobility models that are specialized to certain scenarios. These kinds of mobility models can often be found in special literature or they can be derived from available mobility models, if needed.

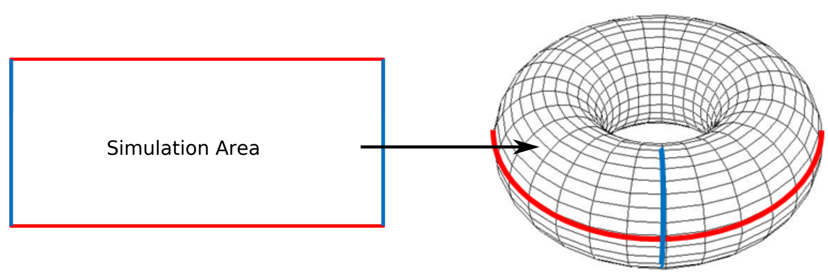

Fig. 1.1: Boundless simulation area

An example of such a special problem is the railway problem where trains run on rails without collisions. Another example is the correlation of movement to technical aspects (feedback). If a cell phone user looses contact to the base station, for instance, he might change his current movement in order to get a better quality of service. In some cases collisions of users are influencing the movement, e.g., avatars of computer games. *Social mobility models* [4], for instance, consider the interactions and relationships between mobile users. Mobility models can also be derived from natural or physical phenomena, e.g. the movement of molecules or fluids.

Sometimes specialized simulation areas are needed in mobility models. The question has to be answered, what happens to the mobile entity, when it reaches the boundary of the simulated area. Possible solutions are, for instance, slowing down, changing direction, or bouncing back. One example for such a special simulation area is the *Boundless Simulation Area* [2]. If a moving entity reaches the border of the simulation area, it appears at the opposite side. Therefore, entities can never reach the boundary of the simulation area. By applying the Boundless Simulation Area algorithm, the simulation area is mapped to a torus. This mapping is illustrated in Figure 1.1. When a Boundless Simulation Area is used, it is important to see that the metric of the mobility model has to be adapted to it.

Another problem related to simulation areas is the appearance of obstacles within the area. The *Obstacle Mobility Model* [1] provides an example for such a specialized simulation area. It allows to define obstacles that directly influence the movement of the entities.

1.3 Mobility Models

This section discusses several examples of widely used mobility models in detail. A more detailed description of the presented mobility models can be found in Camp et al. [2], Bai et al. [1], and Sanchez et al. [5].

The most important properties of the presented models are described and illustrated in figures that show possible movement patterns of the models.

1.3.1 Random Walk Model

The Random Walk Mobility Model is a widely used model that is based on the idea that entities in nature move in unpredictable ways. In this mobility model an entity moves from its current location to a following location by choosing randomly a new direction and speed. Direction and speed are limited to predefined ranges, i.e. they are chosen from [speedmin; speedmax] and $[0;2\pi]$. Every movement is limited to a constant time interval. After a movement, the direction and speed for the next movement is calculated. When the entity reaches the boundary of the simulation area, it bounces off the boundary with an angle that depends on the incoming direction and continues its path. Sometimes the movement is not limited to a constant time interval but to a constant distance.

In Figure 1.2 the Random Walk Mobility Model is illustrated. The square illustrates the simulation area, with the 0/0 coordinate as origin and the relative distance on the X and Y axis to the origin. The walk begins in the

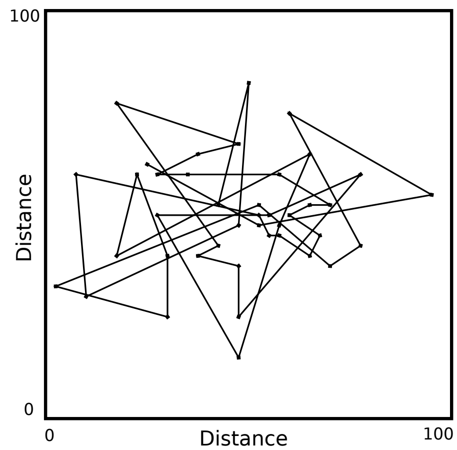

Fig. 1.2: Random Walk Mobility Model with constant time interval

center of a simulation area. It can be seen, that this model utilizes especially the area around the starting point. It can also be seen that the algorithm generates movements with sharp turns and stops, which might be unrealistic for certain scenarios. This is caused by the fact that the Random Walk Mobility Model is a memoryless mobility pattern. In the calculation of the next movement, no knowledge of previous movements is used. The current speed and direction of a movement is completely independent of its past speed and direction.

1.3.2 Random Waypoint Model

The Random Waypoint Mobility Model is also a widely used model and is very similar to the Random Walk Mobility Model. In this mobility model, an entity chooses a random destination coordinate (within the simulation area) and a random speed (from [speedmin; speedmax]). Then it moves from its current location to the destination location. Additionally, the Random Waypoint Mobility Model defines pause times between two movements. After a pause, the new movement is calculated. If pause times are set to zero and the speed ranges are chosen to be similar, the Random Waypoint Mobility Model is identical to the Random Walk Mobility Model

Figure 1.3 illustrates a traveling pattern of an entity that uses the Random Waypoint Mobility Model. It starts in the center of the simulation area. Again, the algorithm generates movements with sharp turns and stops.

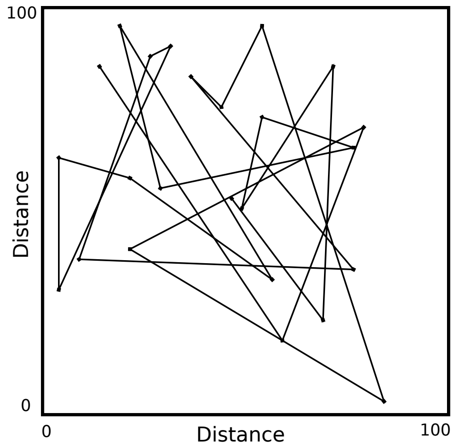

Fig. 1.3: Random Way Point Mobility Model

1.3.3 Random Direction Model

In the Random Direction Mobility Model, an entity chooses a random direction (in the range [0;π]) and a random speed (in the range [speedmin; speedmax]), similar to the Random Walk Mobility Model. The entity moves with the chosen direction and speed towards the boundary of the simulation area until reaching it. There it pauses for a predefined time, before choosing the next direction and speed, to move again.

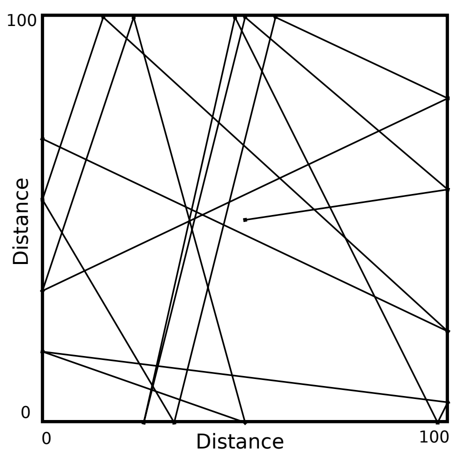

Fig. 1.4: Random Direction Mobility Model

In a variation of this model the entity does not move to the boundary, but stops on its way at some point along the destination path. This behavior can be also simulated using Random Waypoint Mobility Model.

A sample moving pattern for the Random Direction Mobility Model is illustrated in Figure 1.4. It can be seen that in comparison to the Random Walk and the Random Waypoint, the Random Direction Mobility Model utilizes the whole simulation area and is not focused on the center of the area.

1.3.4 Gauss-Markov Model

In the Gauss-Markov Mobility Model the moving entity gets initially assigned a speed and a direction. At fixed intervals of time, an update of direction and speed is applied to the entity. In contradiction to the models described before, the Gauss-Markov Mobility Model enables movements that are depending on previous movements. The degree of dependence on previous movements is adapted by a parameter α (α = [0,1]).

- $\alpha = 0$: The new movement does not depend on previous movement and results similar to the random walk are achieved
- $0 < \alpha < 1$: Intermediate levels of randomness are obtained
- $\alpha = 1$: The entity moves in a linear manner

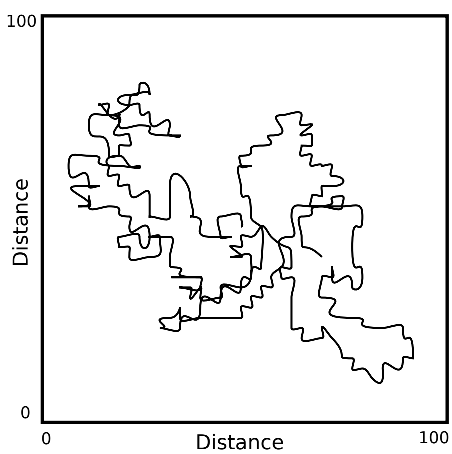

Fig. 1.5: Gauss-Markov Model

Additionally an average speed can be specified for an entity. To avoid collisions with the boundary of the simulation area, the direction of the entity is adapted when it approaches the boundary. When a certain distance to the boundary is met, the entity is forced away from the boundary. The current direction is adapted to directly move away from the boarder as a basis for the calculations of the next step. This avoids, that an entity remains near a boundary for a long period of time.

When the predefined time interval expires, a new direction and speed is calculated, based on the current location, speed and direction. Other implementations of this model with different properties exist.

Figure 1.5 illustrates an example traveling pattern of an entity using the Gauss-Markov Mobility Model, beginning in the center of the simulation area. By adapting the direction and speed updates based on the current direction and speed, the Gauss-Markov Mobility Model does not show the same sharp stops and turns than the mobility models described before.

1.3.5 Manhattan Model

The Manhattan Mobility Model is a widely used model which is based on the idea that the movement of entities is often bound to streets or highways.

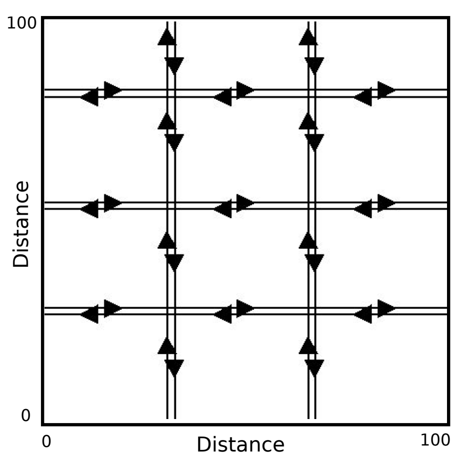

Fig. 1.6: Manhattan Model

A map is specified with streets (both directions) and crossings on which the entities move. A realistic acceleration can be defined (e.g. for cars) and also an average velocity. Additionally a safety distance between two entities is set.

Entities are moving on predefined streets and are changing the street at a crossing with a certain probability. An example configuration is:

– P(onwards) = 0.5
– P(left) = 0.25
– P(right) = 0.25

Figure 1.6 illustrates an example of a map with streets for the Manhattan Mobility Model. A moving entity will move on the predefined streets and change to another street at a crossing with the given probability.

1.3.6 Column Model

The Column Mobility Model is a group mobility model in which each mobile entity follows a *reference point*. Reference points are arranged in a line. The line itself is moving, following an entity mobility model. The angle of the line may be fixed or the line may be rotating. The mobile nodes are not directly approaching the reference points. Instead they are are moving towards a coordinate that is chosen randomly nearby their reference point. Examples for this group mobility model are

– a convoy of trucks which are driving one after another in a row
– or tanks which are side by side approaching an enemy.

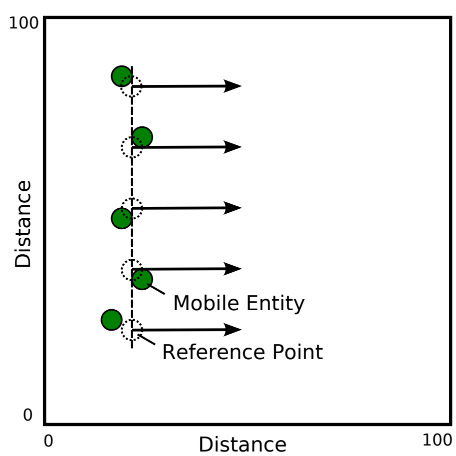

Fig. 1.7: Column Model

Figure 1.8 illustrates the group movement of the Column Mobility Model. It is shown that a group of mobile entities is following reference points on a vertical line. Every mobile node is approaching an own reference point, having small deviations in its direction. The line is moving as a whole, depicted by the direction vectors.

1.3.7 Pursue Model

The Pursue Mobility Model is a group mobility model in which a group of mobile entities is pursuing a single *reference entity*. The reference entity is using an entity mobility model, e.g. the Random Walk Mobility Model. The other entities are pursuing the reference entity, however, small deviations are added to their direction. Additionally, acceleration is simulated in this model. An example of this scenario is a group of tourists which are following a guide in a museum.

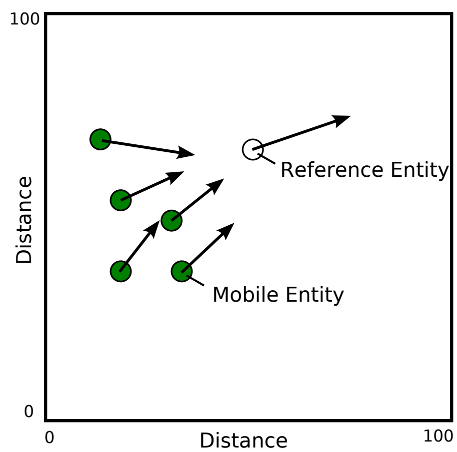

Fig. 1.8: Pursue Model

Figure 1.8 illustrates the group movement of the Pursue Mobility Model. A reference entity is illustrated which is moving in a certain direction (depicted by a vector). The other entities are approaching the reference entity with slightly varying directions (also depicted by vectors).

1.3.8 Nomadic Community Model

In the Nomadic Community Mobility Model the mobile entities are following a single *reference point*. All nodes are sharing the same reference point and are randomly moving around it. The reference point itself is moving, following an an entity mobility model (e.g. Random Walk Mobility Model). When the reference point stops its movement, the mobile nodes are continuing to move around the reference point. Examples for this group mobility model are nomads which are moving from one place to another.

Figure 1.9 illustrates the group movement of the Nomadic Community Mobility Model. A reference entity is illustrated which is moving in a certain

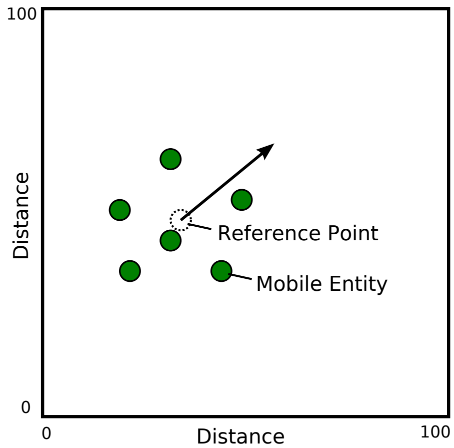

Fig. 1.9: Nomadic Model

direction (depicted by a vector). The other entities are randomly moving around the reference entity.

1.4 Selection of Appropriate Mobility Models

Similar to the use of other simulation models, a trade-off has to be made between the accuracy of a mobility model and its costs. The more accurate a mobility model is and the more it fits to the real-life scenario which is modeled, the more realistic results will be produced. However such realistic mobility models usually impose high complexity. This increases the costs in terms of implementation efforts and also in terms of slow performance in simulations which might be a serious problem. If the mobility model is kept simple on the other hand, its implementation is easy and the algorithms will allow for a good simulation performance. However, the results of the model will be also simplified.

Although the simple models are often used in simulations (e.g. in ad-hoc network research), it is reasonable to adapt the mobility model to the actual problem space. In [2] Camp et al. illustrated that mobility models are significantly influencing the results of simulations. The paper concludes, that the performance of ad-hoc protocols varies significantly under the influence of different mobility models. This implies that it is important to chose a mobility model which actually fits to the described problem. Also in [3] the appropriate selection of well known models for mobility and radio propagation is discussed with respect to the simulation of mobile ad-hoc networks.

Usually it is not a good idea to just take a simple model like the Random Walk without verifying that it fits to the problem. However the simple models can provide a good starting point for simulations. They can also be used as an alternative for more complex models. Results received with complex models can be compared to the results received with simplified models to validate that the behavior of mobile entities actually has impact on the results. However, even the use of a simple model (as described in Section 1.3, needs some thought. Each of the simple models shows different special movement patters that might be more realistic to special scenarios, than others. The Random Direction Model, for instance, utilizes the whole simulation area and is not focused on the center of the area as the Random Walk and the Random Waypoint model.

To find a suitable mobility model for a certain scenario, it is a good idea to review mobility models that solve comparable problems in other scenarios. Either the models can be used directly as they are or they can be adapted to the new problem space. Another approach is to simply use the same mobility models that other researchers use in the same research field (e.g. to investigate mobile ad-hoc network protocols), if possible. This approach provides at least comparability between different solutions for a problem.

1.5 Conclusions

There is a high number of mobility models that are used for simulations in wireless networks. This chapter has presented several categories of mobility models and has described a number of mobility models in detail.

It has been shown that it is important to find the appropriate mobility model for a certain research scenario, because mobility models usually have significant impact on simulation results. The model has to be complex enough to provide representative results and it has to be simple enough to be easily implemented and to provide fast simulation performance.

The most accurate entity movement patterns are, of course, achieved by gathering traces from real moving entities. If available, such traces can also be used to verify the mobility approximation of synthetic mobility models against real user behavior.

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