A VORONOI-BASED MOBILITY MODEL FOR URBAN ENVIRONMENTS

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Abstract - Mobility models are one piece in a chain of models, which are used to simulate mobile communication networks. Thereby, mobility models are generated to create typical movement patterns for nodes in a given environment. The following paper proposes a new mobility model for urban areas. The model contains movement channels, which are calculated by the multiple application of Voronoi graphs. The created environment is combined with a random-based mobility algorithm. Thus, the new Voronoi Mobility Model is generated.

Keywords - Mobility Modeling, Voronoi Graph, Mobile Communication Networks, Ad Hoc Networks, Urban Environment

I. INTRODUCTION

Mobility modeling is an extensively studied field in the domain of mobile communication. Suitable mobility models are necessary in the analysis and simulation of cellular networks and especially ad hoc networks. Thereby, a reasonable compromise between realistic user behavior and complexity has to be found. There are already many propositions for randomly generated movement patterns. In many cases, plain field scenarios are considered. It is difficult to include real building structures in those models and thus to simulate realistic urban scenarios. Especially, as the design of roads, possible obstacles or special attraction points influence and limit the movement behavior of the users in daily environments. Thus, scenarios with uniformly distributed users are certainly well-adapted for theoretical analysis, but not suitable to reflect reality in the necessary way.

Apparently, it is possible to create trace files by the measurement of real scenarios. In doing so, reality is mapped directly into a simulation scenario. However, in this case, flexibility and possibilities to extend the behavior of users are fairly limited. The motivation for the Voronoi Mobility Model is exactly the challenge to provide the needed compromise between reality and complexity. It is the authors’ intention to create an easy, but flexible and realistic tool to generate simulation scenarios for mobile communication in arbitrarily chosen urban scenarios.

For that purpose, section II describes already existing approaches to illustrate merits and vacancies of current mobility models.

Afterwards, section III provides an overview about the Voronoi environment model itself. The Voronoi environment model describes the construction principle of the simulation scenario including buildings and movement channels.

Section IV adds mobility to the given Voronoi environment model. The resulting Voronoi Mobility Model is a proposal for node movements in virtually created, but realistic urban environments.

The final section V sums up this paper. Additionally, it provides an outline how to apply and extend the given ideas.

II. RELATED WORK

When considering mobility models, two basic approaches can be distinguished: On the one hand, there are synthetic models, which generate user movement based on random algorithms. On the other hand, trace files can be used. A corresponding approach to provide mobility models based on trace files is given in [1]. Trace files contain measurement data, which makes traces to be a very precise mirror of a real scenario. However, it is difficult in most cases to even get traces, as measurement campaigns can be very expensive. Additionally, traces are inflexible, as the reconstruction of the same scenario with slightly changed conditions is a hard - or even impossible - challenge. This means that changing parameters e. g. user number, speed, etc., while keeping other parameters is not easily realizable in practice. That’s why most simulations still rely on synthetic models.

A first Random Walk Mobility Model has already been developed in 1926 by Albert Einstein. He used that model to create unpredictable movement patterns. Each node moves from a given position to a new location by choosing direction and speed from a predefined interval $[0, 2\pi]$ and $[\text{minspeed}, \text{maxspeed}]$, respectively. Each movement is executed for a constant time $t$ or defined distance $d$. A node reaching the final position restarts the process anew. In case of collisions with the simulation border, a node is reflected by an angle of reflection, which is equal to its angle of incidence. The application of the Random Walk Mobility Model leads to memoryless movement patterns.

Similarly to the Random Walk Mobility Model, another famous mobility model is given by the Random Waypoint Model. Random Waypoint Model has mainly been taken for research in ad hoc networks. Broch [2], Johnson [3] and Perkins [4], [5], [6] performed many comparisons
of routing protocols using that model. In addition to the previous model, Random Waypoint Model includes pause times between changes in speed or direction. After that waiting period, each node starts movement to a randomly chosen destination point within the simulation area. Again, speed is taken from a uniformly distributed interval between \([\text{minspeed}, \text{maxspeed}]\). The movement pattern is very similar to the previous mentioned one. However, it has been shown by Yoon in [7] and by Bettstetter in [8] that the Random Waypoint Model suffers from its statistical properties. Neither node distribution nor node speed distribution stay constant on average during simulation time. With ongoing time, node distribution tends toward the center of the simulation area and the mean value of the speed distribution decreases significantly.

In order to avoid this fatal behavior of the Random Waypoint Model, the Random Direction Mobility Model has been developed in [9]. Given this model, each node chooses a random direction from \([0, 2\pi]\) and a corresponding speed in \([\text{minspeed}, \text{maxspeed}]\). Once the node reaches the simulation boundary, the waiting time \(t_w\) has to be attended before repeating the whole process of direction and speed selection.

There is also model to describe a predefined road network within the given simulation area. The so-called City Section Mobility Model proposed in [10] defines road specific speed limits as well as waiting points on the given road structure. Nodes follow a predefined path on the road network, which generally consists of a squared network representing streets of a Manhattan-like urban environment.

However, for arbitrary building constellations, it is difficult to provide a predefined path network. Therefore, an Obstacle Mobility Model has been proposed by Jardosh in [11]. Using building corners, a path network is calculated by applying the theory of Voronoi graphs. The Obstacle Mobility Model aims to reflect reality by defining the given movement paths between buildings. A possible scenario is illustrated in Fig. 1. According to that model, node movement is restricted to paths defined by the Voronoi graph. However, movement is restricted to a very unnatural behavior, as most parts of the simulation area can never be entered by the nodes.

A detailed overview and analysis of further, existing mobility models can be found in [12] and [13], respectively.

### III. VORONOI ENVIRONMENT MODEL

The following assumptions and constraints are given for the creation of the new mobility model:

- As most known mobility models consider only plain field scenarios, the new model shall include building structures. This will allow the simulation of realistic urban scenarios.
- There are three major types of movement constraints: First of all, movement can be based on a random process without any limitation to the movement area.
- Secondly, movement channels define areas of movement and thirdly, movement can be restricted to path lines.
- The model shall reflect reality in an adequate way. According to the authors’ understanding, the second approach shall be chosen for that purpose: The new model shall contain movement sectors. Major movement shall take place within that area. However, the movement sectors can be left, if necessary. This thought underlies the idea that real scenarios consist of streets, sidewalks, indoor areas and so on, which can be considered to be movement sectors with different constraints for the users. In real life, user may enter and leave these areas.
- Additionally, it is very important that the model is flexible and can be adjusted to various scenarios. In doing so, the model shall be easy to calculate for arbitrary sets of given building structures.

The Voronoi environment model is a new approach, which fulfills the presented constraints. Based upon this model, a corresponding algorithm for user movement will be proposed in the next section. Together, these two parts build up the new Voronoi Mobility Model.

The Voronoi environment model keeps the idea of using Voronoi graphs to create a movement environment for nodes as presented in [11]. However, on the contrary to the Obstacle Mobility Model, Voronoi environment model defines movement channels instead of movement paths, as this approach corresponds to reality in better way.

First of all, building structures are defined based upon a plain simulation area. Each building is uniquely defined by a given set of corner coordinates. In principle, arbitrary building shapes can thus be realized. The corners are used as Voronoi points for a first calculation of the Voronoi graph. Voronoi graph is named after the Ukrainian mathematics M. G. Voronoi, who found this construction in 1908. Voronoi graph divides an area, which contains a limited number of Voronoi points, into different regions. In doing so, each

![Voronoi path of the Obstacle Mobility Model](https://via.placeholder.com/150)
Fig. 2
first order Voronoi graph with building interpolation depth $x = 3$

region is assigned to a Voronoi point. The special property of the Voronoi diagram is given by the fact that the Euclidean distance between any point within a Voronoi region and the corresponding Voronoi point is minimum in comparison to the distance between this point and any other Voronoi point. Thus, the edges of the Voronoi graph separate different Voronoi regions and have equal distance to at least two Voronoi points. A detailed mathematical treatment of Voronoi graphs can be found e.g. in [14]. Voronoi graphs can be constructed according to the Plane-Sweep Algorithm proposed by Fortune in [15].

Fig. 1 illustrates the Voronoi graph and the corresponding building corners. As clearly visible, the resulting graph has rude shape, as it is only calculated by corners. The Obstacle Mobility Model uses this graph to define movement paths between different buildings. However, the graph seems to be inappropriate for further treatment. That’s why further interpolation points are used to get a finer structure of the Voronoi graph. In doing so, an interpolation factor $x$ defines interpolation depth of a wall between two corners. As a result, $2^x - 1$ additional construction points are generated to define the wall position. If the Voronoi graph is calculated again based upon the refined building structure, a graph as shown in Fig. 2 is generated. It becomes apparent that the new graph disposes of smooth edges in comparison to Fig. 1.

A lot of additional edges have been generated by the interpolation process. It turns out that edges crossing building walls are needless for further processing. Additionally, there are unwanted edges, which do not cross building walls. These edges define branch lines of the main graph and are also deleted. The refinement of the graph results in an intermediate structure as shown in Fig. 3.

A second Voronoi graph can be calculated based upon the merged structure between initial building structure and the first Voronoi graph. Again, an interpolation factor $x$ helps to define additional construction points and to smooth edges later on. The result for $x = 3$ is shown in Fig. 4. Movement sectors between buildings and within buildings are already clearly visible. In a similar way as done before, needless edges are removed. For that purpose, all edges connected to the initial graph are removed as illustrated in Fig. 5.
This structure is taken as basis for the Voronoi environment model. Apparently, there is a major movement channel in the middle between the buildings. Additionally, there are movement sectors within each building.

In principle it is possible to calculate further Voronoi graphs based upon the given structure. A third, fourth or further Voronoi graph could be used to vary channel size between buildings or to define substructures like sidewalks or building access. For the existing calculation of the Voronoi graph, the Euclidean distance measurement has been used. In principle, arbitrary metrics can be taken into account. Thus, size and shape of the movement channels could be changed additionally.

IV. VORONOI MOBILITY MODEL

In this section, a suitable algorithm for node movement is presented, which defines movement based upon the given Voronoi environment model. Together with the Voronoi environment model, it builds up the new Voronoi Mobility Model. There are some requirements, which have to be met by the algorithm in order to provide a good mobility model:

- Node distribution: Nodes are uniformly distributed within the Voronoi channel area, in buildings as well as on the street.
- Movement: The mobile terminals are allowed to move within the channels calculated in section III. At the beginning of the simulation, nodes move with an initial speed \( v \in [0, \text{maxspeed}] \) and a given angle \( \alpha \in [0, 2\pi] \). The movement continues for a given time \( t \). If - within that time - there is a collision with the field border, movement will be continued with an angle of reflection \( \gamma = \beta \), if an angle of incidence \( \beta \) with the field border is provided. The movement of the nodes is mirrored at the perpendicular line of the graph.
- Transition: There is a given probability for entering and leaving the Voronoi channels \( p_{ch} \in [0, 1] \). For \( p_{ch} \) being greater than a threshold probability \( p_{ch, \text{thres}} \), the channel zone can be left. In case of \( p_{ch, \text{thres}} = 1 \), all nodes will stay within the channel areas during the whole simulation. In the presented scheme, it may also happen that a node leaving the channel area encounters a building wall. In that case, a similar proceeding is proposed: When colliding with a wall, a random number \( p_{wall} \in [0, 1] \) is generated. If \( p_{wall} \) is greater than a given threshold probability \( p_{wall, \text{thres}} \), the corresponding node may enter or leave the building. Otherwise, the node is reflected in the same way as it is done at the field border.
- Pause Time: A node shall interrupt movement at a random point of time for a random waiting period. Afterwards, movement is continued with a new angle \( \alpha \) and a new speed \( v \).

The described model is very similar to the mentioned Random Direction Model. Nodes behave like bouncing balls within the movement channels. As the statistical properties of the Random Direction Model are very good, a similar behavior is achieved in here.

The question how to distribute nodes uniformly on the simulation area at the beginning is not so easy to solve. Per definition, mobile terminals have to be distributed on the Voronoi channel area, which is only a part of the whole simulation area. However, it is very difficult to determine, whether a randomly chosen point is within a channel area or not. For that purpose, the usual technique of randomly assigning points within the simulation area can not be applied. The problem of node distribution has to be solved differently: It is known that all points of the first Voronoi graph are within the Voronoi channel area. This results per definition from the calculation process of the second Voronoi graph. Given a random point on the first Voronoi graph, a perpendicular line is constructed. This line cuts the boundary line of the Voronoi channel in two points \( S \) and \( S' \), respectively. Given a random number within \([0, 1]\), a random point \( P \) can be found on the segment between \( S \) and \( S' \). Based upon this construction principle as shown in Fig. 6, all nodes can be placed to random positions in the simulation area.

If the given principles are applied, a movement scenario according to Fig. 7 is created. Fig. 7 illustrates exemplarily the movement paths of three nodes. Given the current implementation, it is possible to generate scenario files, which can be used for further simulations with the network simulator NS-2. The authors consider this first approach as a proof of principle that it is possible to create suitable mobility models with different movement sectors based on Voronoi graphs. Future research will include the refinement of the proposed model.
V. CONCLUSION

The given paper presents a new mobility model based upon Voronoi graphs. Using that model, it is possible to generate urban scenarios with arbitrary building constellations and corresponding user movement patterns. Future work will be divided into two major parts: On the hand, the given model will be used to examine routing issues for mobile communication networks in urban environments. On the other hand, the model shows high potential for extensions and refinement. As already mentioned, it is possible with limited effort to vary street width, to create sectors with individual user behavior, to generate building access corridors or even to enhance the model into a three dimensional scenario. Thus, Voronoi Mobility Model could be able to map sidewalks, streets, building entrances, multistory buildings as well as office workers, pedestrians and car drivers into a common scenario to allow even more realistic simulations in future.

REFERENCES