The Area Graph-based Mobility Model and its Impact on Data Dissemination

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Abstract

When analyzing dissemination protocols in mobile ad-hoc networks the underlying mobility model is an important factor because it strongly influences the performance of these protocols. So far most of the research only deals with homogeneous mobility models like the very common Random Waypoint Mobility Model and the Random Walk Mobility Model. In this paper we introduce a new model, the Area Graph-based Mobility Model, which considers the major characteristics of realistic scenarios such as their heterogeneity. By analyzing the results of experiments using different broadcast protocols we examine the characteristics of the Area Graph-based Mobility Model. Furthermore, we show that in heterogeneous scenarios it is necessary to use adaptive broadcast protocols, otherwise an efficient dissemination in areas with differing topologies and densities is not possible.

1. Introduction

Due to recent developments in computer technology, the issue ”mobility” becomes more and more important. A current example is Mobile Ad-hoc Networks (MANETs), which are decentralized and unstructured peer-to-peer networks and spontaneously built connections among mobile devices, using wireless transmission technologies. A typical characteristic of these networks is their dynamic behavior due to the mobility and unreliability of the network nodes. A MANET has no fixed structure or topology because the connections between the nodes are changing continuously. Hence many of the well known algorithms for static networks can only be used limitedly or sometimes not at all.

A typical and common operation in MANETs is the broadcast (dissemination to all nodes of the network) of data or messages. To simulate the dissemination of data inside a MANET you always need an underlying mobility model which describes the motion of the network nodes. In this paper we introduce a novel heterogeneous mobility model and show the results of an experimental study of broadcast protocols by using this model.

Today many of the studies of MANETs [7, 10] use homogeneous mobility models such as the Random Walk [3] or Random Waypoint Model [1]. Most of these models fail to simulate the characteristics of real scenarios. Other approaches [3, 5] design very specialized mobility models which simulate a specific scenario in a very detailed way. So the experimental results of these models give a very exact picture of the real behavior. However, this specialization is also the drawback of these models because they only give results for a special scenario which often cannot be generalized.

The Area Graph-based Mobility Model introduced in this paper is a model that maintains the main aspects of real scenarios without over-specialization. This mobility model is based on a directed graph with areas of different densities and therefore preserves the heterogeneous structure of real settings. If you take a look at MANETs in real scenarios such as an exhibition or the campus of a university, you will see that there are many buildings and areas such as exhibition halls and lecture auditoriums in contrast to small aisles and long paths each having different network densities.

To show the characteristics of the dissemination behavior of the heterogeneous Area Graph-based Mobility Model we present the results of experimental studies using this model. Furthermore we show the necessity of adaptive protocols in the case of heterogeneous scenarios.

The remainder of the paper is structured as follows: In Section 2 we give a brief overview of the related work. Section 3 presents the examined broadcast protocols and in Section 4 we introduce the novel Area Graph-based Mobility Model. Section 5 discusses the experimental results. We summarize this paper and give an outlook for future work in Section 6.

2. Related Work

Today there are mainly two categories of mobility models: simple homogeneous models and more complex topology-based models.

The most common homogeneous models are the Random Walk Mobility Model [3] and Random Waypoint Mobility Model [1]. They both simulate the motion of nodes on a rectangular area.

In [5] the Obstacle Mobility Model simulates real world topographies with obstacles and pathways. It is also designed to model very specific scenarios and incorporates the propagation of radio signals according to the obstacles placed.

The Graph-based Mobility Model [8] maps the topology of a scenario by using a graph to define the motion of the nodes, but it does not consider clusters with different topologies and densities.

Finally one can observe that current mobility models either create homogeneous areas, or are very specialized solutions that simulate very specific scenarios or topologies. A third approach is the detailed simulation of the exact motion of the nodes, but this does not seem to have a strong impact on the overall results.

What is still missing is a mobility model which maps reality better than the homogeneous ones but also allows more general results than the sophisticated, specialized solutions. In the following sections we try to solve this problem by introducing a mobility model that creates a heterogeneous topology but is easy to configure and results in general statements about tested protocols.

3. Broadcast Protocols

When disseminating data in a network (broadcast) it is the primary goal to reach as many nodes as possible. Furthermore the network load (i.e. number of messages needed to disseminate the data) has to be considered. Especially in mobile networks the network load is a crucial factor because of limited resources (bandwidth, energy). Therefore an efficient broadcast protocol should reach many nodes and should have a small ratio between messages processed and number of nodes reached.

In the following subsections we introduce the broadcast protocols which we use in our experiments. We use very common and relevant broadcast protocols [7, 10] in order to have a good comparison to other related works.

All network nodes are using a message history. The protocols use this history to know whether the data of a message is new or has reached the node before. In the latter case the node will not resend the data to prevent infinite message forwarding.

Simple Flooding When disseminating data using simple flooding [10] a starting node sends the data to all its neighbors, i.e. all directly reachable nodes. Every node which receives this data sends the data to all its neighbors as well. Because of the message history of the nodes the dissemination stops at the latest when the data is delivered to all reachable nodes.

Probabilistic Flooding When disseminating data using probabilistic flooding [10] a starting node broadcasts the data to all its neighbors. Every node which receives the data is only resending it with a given probability p, but when resending the data the node sends it to all its neighbors.

Adaptive Probabilistic Flooding Like the probabilistic flooding the dissemination of adaptive probabilistic flooding is based on a probability value p. Unlike probabilistic flooding the value is not fixed but adapts to the local density of the network. It depends on the number of neighbors n_s of the sending node s and the number of neighbors n_r of the receiving (possibly resending) node r.

The calculation of the probability value p is done by a function that limits the number of resending nodes to a certain value because in dense networks a certain amount of resending nodes is sufficient. This number should be independent of the density and so a threshold value x (> 0) is used to control the number of resending nodes. We chose the following function to represent a simple adaptive protocol:

$$f : (n_s, n_r) \mapsto p = \min\left(1, \frac{x}{\min(n_s, n_r)} \cdot \frac{\max(n_s, n_r)}{\min(n_s, n_r)}\right)$$

This function is explained in detail in [2].

Flooding with Self Pruning Like the adaptive probabilistic flooding, flooding with self pruning [6] uses knowledge about the network neighbors of a node to broadcast the data more efficiently. When a node receives the data it compares the neighbors of the sending node to its own neighbors. If the neighbors of the receiving node are a subset of the neighbors of the sending node, i.e. there is no new node which can be reached, the receiving node does not resend the data. Otherwise it resends the data to all its neighbors.

4. The Area Graph-based Mobility Model

Our proposed Area Graph-based Mobility Model uses a graph as a boundary for the motion of the network nodes. Considering real scenarios you can see that they do not only consist of one area with equal density but of several clusters (with high density) and fixed paths (with low density) between them. The characteristics of these scenarios are preserved by the Area Graph-based Mobility Model.

An area graph is a directed and weighted graph. It consists of several rectangular planes (vertices) and direct connections (edges) between them. The clusters are vertices

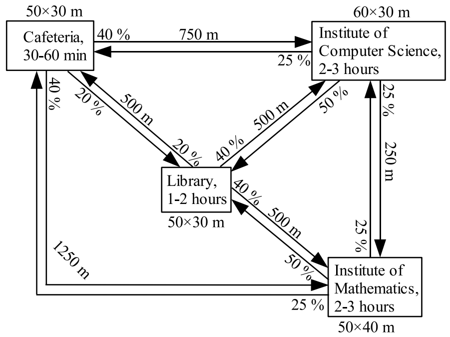


Figure 1. Example of an area graph.

and the paths are edges of an area graph. The weight of an edge is the probability of a network node choosing this edge when leaving the vertex. So the sum of the weights of all outgoing edges of a vertex is always 1. Every vertex of the area graph is given an interval which is used to determine the waiting time inside this vertex. The waiting time is chosen uniformly distributed from this interval.

The motion in the Area Graph-based Mobility Model consists of two parts: Motion inside vertices and motion between vertices. The motion inside vertices is determined by the Random Waypoint Mobility Model. Other mobility models (see [3]) could also be used. The model for the motion between vertices behaves as follows: When a network node enters a vertex of the area graph the waiting time inside this vertex is determined randomly. When the waiting time is exceeded, an outgoing edge is chosen randomly, considering to the weights of the edges. Then the network node moves to the connection point of the vertex and the edge and thereafter moves with a randomly determined speed to the chosen vertex.

We now show an example to give a better understanding of the model. In Fig. 1 you can see a part of a typical campus of a university. We assume that the students use PDAs to communicate. There are two institutes, a cafeteria and a library. In the library the students stay 1 - 2 hours, in the institutes they stay 2 - 3 hours and they pause 30 - 60 minutes in the cafeteria. In this example the probabilities of the edges represent the students' behavior, e.g. on average 40% of the students leaving the library go to the Institute of Computer Science, 40% go to the Institute of Mathematics and 20% go to the cafeteria. The areas of the buildings and the distances between them are pictured as the sizes of the rectangles and the lengths of the connections.

This behavior of the students results in 4 clusters and 6 connections between them as can be seen in Fig. 1. With the help of the Area Graph-based Mobility Model we can simulate this behavior of the students and retrieve their typical distribution on the campus.

Although it is possible to construct an area-graph that is close to a real scenario we avoid over-specialization in our experiments to get more general results about the influence of heterogeneity.

5. Experimental Studies

In this section we show the results of our experimental studies using the previously described Area Graph-based Mobility Model. We tested the following protocols: simple flooding, flooding with self pruning, probabilistic flooding with probabilities p of 20%, 40%, 60% and 80% and adaptive probabilistic flooding with threshold values x of 5, 6, 7, 8, 9 and 10. In the experiments we consider the following values to compare the protocols:

- **Delivery ratio:** The delivery ratio (relative number of nodes reached) indicates how much the data is spread throughout the network by the protocol.
- **Message ratio:** The message ratio (ratio between messages processed and number of nodes reached) shows the efficiency of a particular protocol, i.e. the less messages a protocol needs the better its efficiency.

We ran our experiments to compare broadcast protocols in different settings. Thus we obtain information about the influence of the mobility model on the efficiency of the protocols.

5.1. Parameters

Our experimental studies have been done using the simulator OMNeT++ [9]. The simulated network utilizes an IEEE 802.11 conform MAC protocol. This MAC protocol follows a *Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)* scheme. Furthermore we assume that every node has knowledge about the quantity (used by adaptive probabilistic flooding) and addresses (used by flooding with self pruning) of its neighbors.

For every experiment, i.e. combination of protocol and sub-scenario, we present the mean values of 500 single runs. In every single run we analyze the data dissemination from a randomly chosen starting node. We use 2000 network nodes with a transmission range of 30 m. We further assume a bandwidth of 11 Mbit/s and a message size of 400 byte of user data.

5.2. Experiments

In this subsection we describe our experiments using the Area Graph-based Mobility Model and show their results. Although the Area Graph-based Mobility Model can be used to describe scenarios very detailed, here our goal is

Table 1. Density of the sub-scenarios

Area size	Waiting time	Ø no. of neighbors		
		paths	clusters	total
200×200 m	300-700 s	20.9	32.7	29.0
200×200 m	1000-1400 s	11.7	30.3	27.1
300×300 m	300-700 s	20.2	24.1	22.9
300×300 m	1000-1400 s	11.2	18.6	17.4

to extract general information about the behavior of protocols in heterogeneous scenarios. So we avoid using a special graph as in Fig. 1.

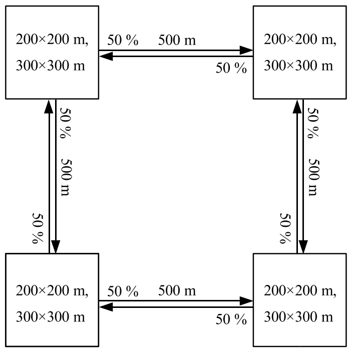


Figure 2. Circular area graph.

For these experiments we used a scenario with 4 clusters and 4 connections which is shown in Fig. 2. The clusters and the connections are arranged in a circular way.

The four tested sub-scenarios and their measured densities are given in Table 1. The speed of the nodes is 1 - 4 $\frac{\text{m}}{\text{s}}$.

The main difference to the scenario using the Random Waypoint Mobility Model described in [2] is the heterogeneity of this scenario. Every sub-scenario includes several areas with different topologies (plane, line) and densities. The results of the experiments are shown in Fig. 3.

Looking at the delivery ratios you can observe that in the two sub-scenarios with a low density on the paths (Fig. 3(c), Fig. 3(d)) at least 25% - 30% of the nodes have not been reached. In the sub-scenarios with a high density on the paths(Fig. 3(a), Fig. 3(b)) only one of the probabilistic protocols (p = 80%) has a delivery ratio similar to flooding (2 - 3% less). In the sub-scenarios with a low density on the paths no probabilistic protocol has an acceptable delivery ratio. Thus none of the probabilistic protocols has an acceptable delivery ratio across all sub-scenarios. Flooding has a good delivery ratio but its message ratio is much higher (factor 1.5 to 2.5) than the message ratio of adaptive probabilistic protocols having a similar delivery ratio. The self pruning protocol shows no significant difference to simple flooding.

The adaptive probabilistic protocols with threshold values x of 9 and 10 are having delivery ratios similar (maximal 7% and 5% less respectively) to flooding. All other adaptive probabilistic protocols have lower delivery ratios.

Altogether the results of this scenario show that the adaptive probabilistic protocols with threshold values x of 9 and 10 are the only efficient protocols. All other protocols either have a low delivery ratio or high message ratio.

Only adaptive probabilistic protocols have proven efficient in the experiments. This is a strong contrast to results of experiments using the Random Waypoint Mobility Model, where some of the probabilistic protocols also showed an efficient behavior [2].

6. Conclusions and Future Work

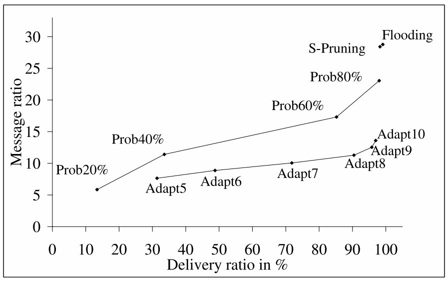
In this paper we introduced our novel Area Graph-based Mobility Model which uses a graph-like structure of connected areas to build up scenarios which maintain the major aspects of real settings. To obtain general results we avoided modeling specific scenarios in detail, as it is done by other mobility models. To show the characteristics of our novel model we examined data dissemination by making several experiments with common broadcast protocols. In these experiments we especially focused on the heterogeneity of realistic scenarios and therefore used the Area Graph-based Mobility Model. For a comparison to previous works the same experiments were also done using the Random Waypoint Mobility Model [2].

The experiments showed that the performance of the examined protocols strongly depends on the underlying mobility model. Some protocols performed well using the homogeneous Random Waypoint Mobility Model but poorly when using the heterogeneous Area Graph-based Mobility Model. The main reason for this is that in contrast to the Random Waypoint Mobility Model the Area Graph-based Mobility Model consists of areas with differing topologies and densities.

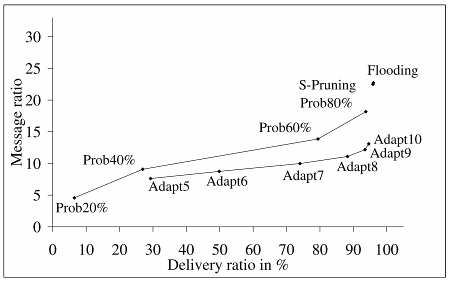
Furthermore we showed that it is necessary to use adaptive broadcast protocols when using heterogeneous mobility models like the Area Graph-based Mobility Model, because an efficient broadcast is not possible without an adaptation to the local network density. However, there is still a need to enhance the adaptive protocols because in different scenarios different threshold values produce optimal results. The adaptation of the threshold value might be a possible solution for that problem.

For a further examination of the Area Graph-based Mobility Model we plan more experiments in the future. In these experiments we will examine both new scenarios and more protocols. The focus will be on more sophisticated protocols with neighbor knowledge and on area-based protocols [7].

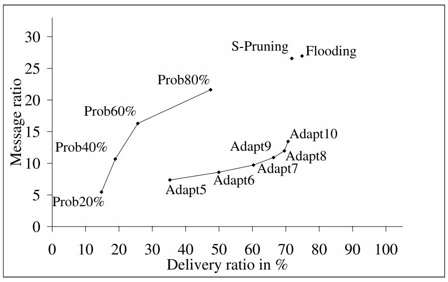
In these experiments we will also examine scenarios with



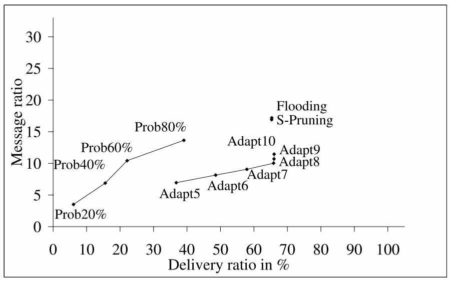
(a) 200×200 m, short waiting time.



(b) 300×300 m, short waiting time.



(c) 200×200 m, long waiting time.



(d) 300×300 m, long waiting time.

Figure 3. Results using the circular area graph.

more complex area graphs with more clusters and paths. Other experiments will focus on scenarios with very low densities resulting in more frequent network partitions.

In parallel we will try to develop a theoretical model for our Area Graph-based Mobility Model to predict the behavior of the dissemination. We will focus on ideas from probabilistic and percolation theory [4] because they seem promising for developing this theoretical model.

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