

# Designing Mobility Models based on Social Network Theory

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*Validation of mobile ad hoc network protocols relies almost exclusively on simulation. The value of the validation is, therefore, highly dependent on how realistic the movement models used in the simulations are. Since there is a very limited number of available real traces in the public domain, synthetic models for movement pattern generation must be used. However, most widely used models are currently very simplistic, their focus being ease of implementation rather than soundness of foundation. Simulation results of protocols are often based on randomly generated movement patterns and, therefore, may differ considerably from those that can be obtained by deploying the system in real scenarios. Movement is strongly affected by the needs of humans to socialise or cooperate, in one form or another. Fortunately, humans are known to associate in particular ways that can be mathematically modelled and that have been studied in social sciences for years.*

*In this paper we propose a new mobility model founded on social network theory. The model allows collections of hosts to be grouped together in a way that is based on social relationships among the individuals. This clustering is then mapped to a topographical space, with movements influenced by the strength of social ties that may also change in time. We have validated our model with real traces by showing that the synthetic mobility traces are a very good approximation of human movement patterns. The impact of the adoption of the proposed algorithm on the performance of AODV and DSR is also presented and discussed.*

## I. Introduction

The definition of realistic mobility models is one of the most critical and, at the same time, difficult aspects of the simulation of applications and systems designed for mobile environments. Currently, there are very few and very recent public data banks capturing node movement in real large-scale mobile ad hoc environments.

For example, researchers at Intel Research Laboratory in Cambridge and the University of Cambridge distributed Bluetooth devices to people, in order to collect data about human movements and to study the characteristics of the co-location patterns among people. These experiments were firstly conducted among students and researchers in Cambridge [5] and then among the participants of InfoCom 2005 [11]. Other similar projects are the Wireless Topology Discovery project at the UCSD [17] and the campus-wide Wave-Lan traffic measurement and analysis exercises that have been carried out at Dartmouth College [7]. At this institution, a project with the aim of creating a repository of publicly available traces for the mobile networking community has also been started [14].

Until now, in general, real movement traces have

been rarely used for evaluation and testing of protocols and systems for mobile networks, with the only exception of [25] and [10], in which the authors used, respectively, the movement traces collected from a campus scenario and direct empirical observations of the movements of pedestrians in downtown Osaka as a basis of the design of their models.

In general, synthetic models have been largely preferred [4]. The reasons of this choice are many. First of all, as mentioned, the available data are limited. Second, these traces are related to very specific scenarios and their validity is difficult to generalise. However, as we will discuss later in the paper, these data show surprising common statistical characteristics, such as the same distribution of the duration of the contacts and inter-contacts intervals. Third, the available traces do not allow for sensitivity analysis of the performance of the algorithm, since the values of the parameters that characterise the simulation scenarios, such as the distribution of the speed or the density of the hosts, cannot be varied. Finally, in some cases, it may be important to have a mathematical model that underlines the movement of the hosts in simulations, in order to study its impact on the design of protocols and systems.

Many mobility models for the generation of synthetic traces have been presented (a survey can be found in [4]). The most widely used of such models are based on random individual movement; the simplest, the Random Walk mobility model (equivalent to Brownian motion), is used to represent pure random movements of the entities of a system [6]. A slight enhancement of this is the Random Way-Point mobility model [13], in which pauses are introduced between changes in direction or speed. More recently, a large number of more sophisticated mobility models for ad hoc network research have been presented [2, 12, 15].

However, all synthetic movement models are suspect because it is quite difficult to assess to what extent they map reality. It is not hard to see, even only with empirical observations, that the random mobility models generate behaviour that is most unhuman-like. This analysis is confirmed by the examination of the available real traces. As we will discuss later in this paper, mobility models based on random mechanisms generate traces that show properties (such as the duration of the contacts between the mobile nodes and the inter-contacts time) very distant from those extracted from real scenarios.

Our work is based on a simple observation. In mobile ad hoc networks, mobile devices are usually carried by humans, so the movement of such devices is necessarily based on human decisions and socialisation behaviour. For instance, it is important to model the behaviour of individuals moving in groups and between groups, as clustering is likely in the typical ad hoc networking deployment scenarios of disaster relief teams, platoons of soldiers, groups of vehicles, etc. In order to capture this type of behaviour, we define a model for group mobility that is heavily dependent on the structure of the relationships among the people carrying the devices. Existing group mobility models fail to capture this social dimension [4].

Fortunately, in recent years, social networks have been investigated in considerable detail, both in sociology and in other areas, most notably mathematics and physics. In fact, in the recent years, various types of networks (such as the Internet, the World Wide Web and biological networks) have been investigated by researchers especially in the statistical physics community. Theoretical models have been developed to reproduce the properties of these networks, such as the so-called small worlds model proposed by Watts and Strogatz [26] or various scale-free models [19].

However, as discussed by Newman and Park in [21], social networks appear to be fundamentally different from other types of networked systems. In

particular, even if social networks present typical small-worlds behaviour in terms of the average distance between pairs of individuals (the so-called *average path length*), they show a greater level of clustering. In particular, in [21] the authors observe that the level of clustering seen in many non-social systems is no greater than in those generated using pure random models. Instead in social networks, clustering appears to be far greater than in networks based on stochastic models. The authors suggest that this is strictly related to the fact that humans usually organise themselves into *communities*.

In this paper, we propose a new mobility model that is founded on social network theory. One of the inputs of the mobility model is the social network of the individuals carrying the mobile devices. This network can be generated synthetically using these results [26]. The model allows collections of hosts to be grouped together in a way that is based on social relationships among the individuals. This grouping is only then mapped to a topographical space, with topography biased by the strength of social ties. The movements of the hosts are also driven by the social relationships among them. The model also allows for the definition of different types of relationships during a certain period of time (i.e., a day or a week). For instance, it might be important to be able to describe that in the morning and in the afternoon of weekdays, relationships at the workplace are more important than friendships and family one, whereas the opposite is true during the evenings and weekends.

We evaluate our model using real mobility traces provided by Intel Research and we show that the model provides a good approximation of real movements in terms of some fundamental parameters, such as the distribution of the contacts duration and inter-contacts time. In particular, the data show that an approximate power law holds over a large range of values for the inter-contacts time. Instead, contacts duration distribution follows a power law for a more limited range. These characteristics of distribution are also very similar to those observed by the researchers at the University of California at San Diego and Dartmouth College [5]<sup>1</sup>.

The paper has the following structure: Section II shows how these results can be used to design a social network founded mobility model. Section III illustrates the results of the evaluation of the model

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<sup>1</sup>It is interesting to observe that this behaviour seems not strongly related to geographical location, but only on human relationships. The traces from Dartmouth College and UCSD are related to an AP-based infrastructure, whereas the traces from Intel are from an infrastructure-less ad hoc network.

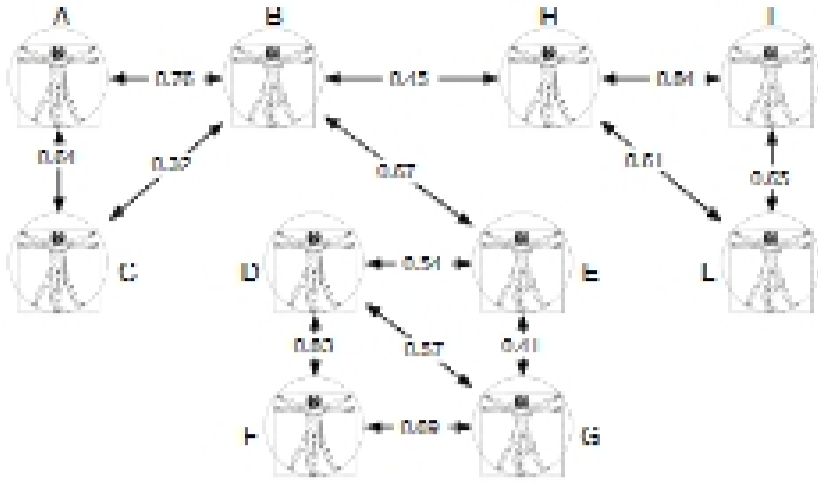


Figure 1: Example of social network.

based on the comparison with real traces; some simulation results about the impact of the proposed mobility model on the performance of the AODV and DSR protocols are also discussed. In Section IV we compare the proposed mobility model with the current state of the art. Section V concludes the paper, summarising the original contribution of our work.

## II. Design of the Mobility Model

In this section we show how we designed a mobility model which is founded on the results of social network theories briefly introduced. The description of the mobility model, mirroring its conceptual steps, is organised as follows:

- Firstly, we describe how we model social relationships and, in particular, how we use *social networks as input* of the mobility model.
- Secondly, we present the *establishment of the model*: we discuss how we identify communities and groups in the network and how the communities are associated to a geographical space. Our observation here is that people with strong social links are likely to be geographically colocated often or from time to time.
- Thirdly, we describe the algorithm that is at the basis of the *dynamics* of the nodes, that, again, is based on the strength of social relationships. We argue that individuals with strong social relationships move towards (or within) the same geographical area.
- We show the influence of the choice of the proposed mobility model on the performance of

## II.A. Using Social Networks as Input of the Mobility Model

### II.A.1. Modelling Social Relationships

One of the classic ways of representing social networks is *weighted graphs*. An example of social network is represented in Figure 1. Each node represents one person. The weights associated with each edge of the network is used to model the strength of the interactions between individuals [23]. It is our explicit assumption that these weights, which are expressed as a measure of the strength of social ties, can also be read as a measure of the likelihood of geographic colocation, though the relationship between these quantities is not necessarily a simple one, as will become apparent. We model the degree of social interaction between two people using a value in the range  $[0, 1]$ . 0 indicates no interaction; 1 indicates a strong social interaction. Different social networks can be valid for different parts of a day or of a week<sup>2</sup>.

As a consequence, the network in Figure 1 can be represented by the  $10 \times 10$  symmetric matrix  $M$  showed in Figure 2, where the names of nodes correspond to both rows and columns and are ordered alphabetically. We refer to the matrix representing the social relationships as *Interaction Matrix*. The generic

$$M = \begin{bmatrix} 1 & 0.76 & 0.64 & 0.11 & 0.05 & 0 & 0 & 0.12 & 0.15 & 0 \\ 0.76 & 1 & 0.32 & 0 & 0.67 & 0.13 & 0.23 & 0.45 & 0 & 0.05 \\ 0.64 & 0.32 & 1 & 0.13 & 0.25 & 0 & 0 & 0.15 & 0 & 0 \\ 0.11 & 0 & 0.13 & 1 & 0.54 & 0.83 & 0.57 & 0 & 0 & 0 \\ 0.05 & 0.67 & 0.25 & 0.54 & 1 & 0.2 & 0.41 & 0.2 & 0.23 & 0 \\ 0 & 0.13 & 0 & 0.83 & 0.2 & 1 & 0.69 & 0.15 & 0 & 0 \\ 0 & 0.23 & 0 & 0.57 & 0.41 & 0.69 & 1 & 0.18 & 0 & 0.12 \\ 0.12 & 0.45 & 0.15 & 0 & 0.2 & 0.15 & 0.18 & 1 & 0.84 & 0.61 \\ 0.15 & 0 & 0 & 0 & 0.23 & 0 & 0 & 0.84 & 1 & 0.65 \\ 0 & 0.05 & 0 & 0 & 0 & 0 & 0.12 & 0.61 & 0.65 & 1 \end{bmatrix}$$

Figure 2: Example of an Interaction Matrix representing a simple social network.

element  $m_{i,j}$  represents the interaction between two individuals  $i$  and  $j$ . We refer to the elements of the matrix as the *interaction indicators*. The diagonal elements represent the relationships that an individual has with himself and are set, conventionally, to 1. In Figure 1, we have represented only the links associated to a weight equal to or higher than 0.25.

<sup>2</sup>Let us consider a family of three people, with one child. During the days, when the child is at school and the parents at their workplaces, their social relationship is weak (i.e., represented with low values in the matrix). During the evening, the social ties are stronger as the family members tend to be co-located (i.e., high values in the matrix). The relationship between two colleagues sharing the same office will be represented with a value higher than these family relationships during the working hours in week days.