SIMULATING REALISTIC MOBILITY MODELS FOR LARGE HETEROGENEOUS MANETS

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Abstract
Mobile ad hoc networks (MANETs) are composed of communicating mobile devices capable of spontaneously interconnecting without any pre-existing infrastructure. The wide spread of mobile devices (i.e. phones, PDAs, laptops) enables the deployment of metropolitan ad hoc networks, referred to as MobileMANs. Until recently, MobileMAN simulation suffered from a lack of appropriate tools. Therefore a new class of simulators dedicated to MobileMANs is appearing. This paper presents Madhoc, a MANETs simulator which belongs to this class. In addition to providing particular models for the simulation of numerous nodes evolving in a metropolitan environment, Madhoc comes with appropriate tools for the development and the monitoring of ad hoc applications. Madhoc’s applications are presented.

1. Introduction
A multi-hop mobile ad hoc wireless network (MANET) is a set of mobile nodes which communicate with other nodes in their surround-
ings. These communications, which use the radio medium, happen in a peer-to-peer manner, without relying on any predefined infrastructure. MANETs are commonly said to be self-organizing. Possible applications for MANETs are environmental and medical monitoring, groupware and conferencing, emergency systems, gaming, advertising, customer-to-customer applications, etc. An extensive study of mobile ad hoc networking, related technologies and protocols was proposed by Chlamtac et al. [8].

This paper mostly considers MobileMANs [9], which are MANETs dynamically appearing out of the interactions of the citizens’ devices. MobileMANs exhibit peculiar topological and dynamical configurations. More precisely, the distribution of their nodes ranges from heavily dense to sparse, and the mobility of the nodes is hardly predictable. Moreover they generally gather loads of nodes evolving in large areas. One more issue is that the nodes vary in terms of the networking technologies they use: the network is then said “heterogeneous”.

The investigation of MANETs cannot be achieved only using testbeds. The lack of flexibility of testbeds makes simulation unavoidable. But simulators have drawbacks. More precisely, they are inherently complex and they generally require huge computational resources to execute. Simulating MobileMAN implies even more issues: metropolitan mobility currently is not simulated with a satisfactory level of detail and current simulators do not allow the representation of large-enough networks. Therefore it is usual that researchers working on MobileMAN-related issues are led to develop custom simulators.

This paper presents Mad_hoc, a novel MANET simulator which, by allowing the simulation of large heterogeneous networks, by featuring standard and mobility models based on human behavior, is a contribution to MobileMANs simulation. Section 1.2 gives an overview of the simulation of mobile ad hoc networks. Section 1.3 describes the goals, the detailed architecture of the Mad_hoc simulator and emphasizes its specificities, that are the simulation of heterogeneous networks (section 1.3.3) and the reproduction of metropolitan mobility (section 1.3.4). Finally, before concluding, last section presents an overview of the applications for which Mad_hoc is being used.

2. The evolution of MANETs simulation

Testbeds are experimental networks built and used for research purpose. They are surveyed in [10]. In a mobile ad hoc network, the notions of location and distance between nodes are of prime importance; therefore real testbeds should be deployed at the scale of a city. What prevents—or at least empedes—this is the cost and the inherent lack of flexibility of testbeds. Consequently, software simulation turns out to be a viable alternative and a widely used solution.

Let us highlight the following simulators: ns-2 [1] is the de facto standard for network simulation. It is developed at ISI (California, USA) and is supported by DARPA and NSF. ns-2 was primarily designed to simulate wired networks. The Monarch CMU
projects [21] made available an implementation of the IEEE802.11 layers while the BlueHoc [18] and BlueWare [4] projects focused on the Bluetooth ones. GloMoSim [28] is developed at UCLA (California, USA). It is a parallel (SMP) simulator for wireless networks written in Parsec [3]. GTNets [25] is developed at GeorgiaTech institute (Atlanta, USA). It supports the distribution of a single simulation on a network of workstations. OPNet [11] was first proposed by MIT in 1986. It is now the most widely used commercial network simulator. QualNet [22] is a commercial ad hoc network simulator based on GloMoSim’s core. It extends GloMoSim by bringing support and a set of user-friendly tools. SWANS [5], developed at Cornell university (New York, USA), is built atop the JiST discrete event platform.

With the evolution of MANET research, a new class of simulators is coming along. These recent tools focus on the simulation of metropolitan mobility and/or on large networks. These simulators often operate at the application-level, which means that they implement few details—if any—for the lowest layers of the network stack. Such simulators include NAB [14](EPFL, Lausanne, Switzerland), Jane [20](Trier University, Germany), and DIANEmu [17](Karlsruhe University, Germany). Madhoc belongs to this new class of simulators.

3. **The Madhoc simulator**

Madhoc is being developed at Luxembourg University, in tight collaboration with the University of Le Havre (France). Its development started in 2003.

3.1 **Key features**

The Madhoc simulator aims:

- at reproducing Metropolitan Mobility. So far, most research on broadcasting over MANETs relied on the random waypoint mobility model [27], whose harm has been recently highlighted. Random Waypoint clearly fails at simulating metropolitan mobility and more recent proposals [6, 15, 16, 23] have still not reached a satisfactory level of realism.

- at modelling heterogeneous networks. MobileMAN are populated with devices of different kinds that use several radio technologies (RCT). Currently, most studies consider full-IEEE802.11 networks. Section 1.3.3 shows that heterogeneity is a significant feature of MANETs;

- at enabling the simulation very large dynamic networks. As studied by Riley and Ammar [24], there exists a threshold (of the number of stations in the network) for which the results obtained no longer vary as the number of stations increases. Experimenting MANETs requires that this threshold (that may be big) can be reached.

- at providing a comprehensive and extensible simulation framework;

- To facilitate experiments by providing handy visualization capabilities. This is of paramount importance in the case of ad hoc applications, whose highly distributed nature hardens the development.
3.2 The network model

On the one hand, Mad_hoc models the components at the highest layers of the network stack, resorting to object-oriented modelling. This is the case for the basic structure of the network, which include the nodes, the applications they execute, the connections between them, the messages emitted by the applications thought the connections, the input/output message queues, etc.

On the other hand, at the lowest layers, Mad_hoc uses a probabilistic model which aims at reproducing the impact of physical-level phenomena on the higher layers. Using this strategy, Mad_hoc models packet collisions, signal interferences, and signal attenuation. Extensively using such a probabilistic approach makes the simulator to execute faster, while ensuring a reasonable degree of detail.

The model of Mad_hoc is articulated around the concepts of node, edge, network, environment, devices, radio communication technology (RCT), as detailed in the following.

Nodes. Every node represents a device which:
- runs several applications simultaneously.
- communicate to the other nodes nearby.
- is mobile. Every node is then located in its environment in terms of its 2-dimensional coordinates. Nodes move according to the rules defined by the mobility model they obey.

Edges. An edge of the network graph is a communication link between two nodes. The presence of obstacles to the propagation of
Radio-communication technology. Several radio-communication technologies for wireless networks have been proposed: Wi-Fi (IEEE 802.11 version a, b, or g) and HiperLAN suit well local area networking (LAN). WiMax (IEEE 802.16) is designed for broadband wireless access, it hence fits the needs of metropolitan area networking (MAN). Bluetooth, ZigBee and Wireless USB (WUSB) are designed for Wireless Personal Area Networking (WPAN).

\textit{Mad_hoc} provides the user with the ability to define the characteristics of the communication technologies he/she wishes to use: he can reuse predefined technologies as well as define his own. A RCT is defined by the following properties:

- the maximum transfer rate. The maximum transfer rate is the data-transfer speed obtained when the radio signal is not attenuated and when the link is free of interferences.
- the coverage radius. RCTs operates in a given coverage radius, that is the maximum distance from the source from which the signal can be sensed and demodulated.
- the packet size, which is the smallest contiguous chunk of data that transits between two devices.
- the set of RCTs with which interferences occur.
- number of simultaneous connections that can be established by one network interface.

Network interface. Nodes embed a set of network interfaces, each implementing a given RCT. Additionally, \textit{Mad_hoc} considers that network interfaces may embed antennas or amplifiers. This heterogeneity of radio communication technologies makes it possible for two given nodes to be connected through several connections. In other words, the network graph is a multi-graph.

Environment. The environment, which models the physical terrain in which the nodes evolve, has an impact on the way they move and on the way they communicate: obstacles to mobility (like walls) generally also attenuate the propagation of the radio waves.

3.3 Simulating heterogeneous networks

So far, most studies resorting to MANETs simulations have drawn conclusions on the basis of homogeneous networks. More precisely, it is often conjectured that network nodes use one single networking technology—generally IEEE 802.11b—and that radio signals are all emitted with the same strength. However one of the most relevant characteristics of metropolitan MANETs is their intrinsic heterogene-
ity. Indeed, communication in the MANETs is already possible through various protocols implemented in a wide variety of dissimilar network adapters. Currently available protocols are Bluetooth and IEEE802.11 but it is very likely that new technologies such as Wireless USB (WUSB) and WiMax will come along in the future.

In order to evaluate the connectivity of the network graph, we chose to look at its degree distribution, which gives the number (resp. the ratio) of occurrences of all values for the degree (resp. the number of connections for one node) in a given graph (resp. network). By measuring the degree distribution of typical instances of an homogeneous network as well as an heterogeneous one not only we could observe quantitative but also qualitative differences, as illustrated in figure 3. Quantitative variations are explainable by the fact that distinct RCTs feature different coverage radius. Qualitative variations are observed on the value of the distribution for small values of the degree (e.g less than two). Indeed when the distribution degree of an homogeneous network tends to zero, its tends to its greatest values if the network is heterogeneous. Practically, this means that in homogeneous networks almost no node has no connections to others, while in heterogeneous networks, the majority of them are actually isolated.

In order to make obvious the importance of the consideration of heterogeneity, we executed the same application both on homogeneous and heterogeneous networks. The application retained is a message broadcasting using the DFCN protocol [13]. In order to study the difference of the two processes, we look at the variation of the network coverage along time; that is the variation on time of the ratio of the nodes that have received the message being broadcasted. We then observed that heterogeneity slows down by a factor of about 10 the broadcasting process.
3.4 Mobility and radio propagation models: the environment

Since recently most studies rely on randomized mobility models, especially on the harmful Random Waypoint Mobility Model [27]. A recent effort towards realistic mobility models can be observed in the literature [15], [6]. Surveys of mobility models can be found in [7][6].

\textit{Mad hoc} belongs to a family of tools which aim at reproducing the metropolitan mobility. So far, attempts at modelling metropolitan mobility focus on specific configurations or were based on a some predefined environmental information (traces, for instance). The Manhattan, the city-section and the graph-based mobility models are some examples [7]. The difficulty here is to build a mobility model which has a wide variety of configurations, and that is not computation-intensive. \textit{Mad hoc} features such a mobility model: the human mobility model.

3.5 The Human Mobility Model (HMM)

The human mobility model (HMM) considers an environment made of several spots. A spot is a place where nodes go and stay for some time. It may, for example, represent a shop, a crossroads, a toll, etc. A given node moves from spot to spot by maintaining a list of the spots it has not yet visited. When it exits a spot, the node heads toward the closest non-visited spot. Once all spots have been visited, the node assumes that no spot were actually visited and hence starts from the beginning.

HMM comes with a set of parameters which allow to set the density of spots in the environment, the way these spots are organized (randomly...
Figure 4. (a) The graph resulting of the simulation of 2,000 nodes roaming in a 1km² area. Nodes have either IEEE802.11b or a Bluetooth interface, with the same probability. (b) The graph resulting of the simulation of 400 nodes walking in a 200 × 200m shopping mall. Most of the nodes have a Bluetooth network interface. Some of them have a IEEE802.11 one. (c) The interconnection graph resulting of the simulation of 100 nodes driving on a 3 kilometers-long highway section. Most of the nodes have a Bluetooth as well as a IEEE802.11 one.

or following a grid-like structure), the size of the spot, the minimum and maximum distance between them. Moreover, it allows the definition of the speed of the device moving outside or inside spots. By modifying these parameters, it is possible to construct a wide variety of network scenarios. Among them, we emphasize three scenarios illustrated in figure 4.

**City-center scenario.** The city-center environment (figure 4a) represents people walking and driving in the streets of a city center. The spots stand for crossroads. They are located according to a grid-like structure. Their location is then slightly randomly modified using an amplitude specified by the researcher. Nodes move faster outside of the spots than inside. The city-center scenario generates both dense and sparse regions. It then allows to check if the protocol can adapt to a constantly varying connectivity or not.

**Mall scenario.** The mall scenario (figure 4b) represents people wandering within a shopping mall. The spots stand for shops. They are located randomly with a constraint for non-overlapping. The mall scenario can generate highly dense wide areas. It allows to study the behavior of protocols in dense network conditions.

**Highway scenario.** The highway scenario (figure 4c) represents people driving on the axis of a highway. The spots do not stand for anything real. They are a way of constraining the movement of nodes. As the nodes move very fast, the duration of connections is very short. The highway scenario then allows to check if an application is opportunistic enough.
4. Applications

This section presents some applications of the Mad_hoc simulator.

4.1 Broadcasting Algorithm Development

Mad_hoc comes with a library of the standard and efficient fully localized broadcasting protocols [26], that is: Simple Flooding, Flooding With Self-Pruning, SBA, Multipoint Relaying, AHBP-EX. The library was used for the evaluation and comparison of a new broadcasting protocol dedicated to wireless ad hoc networks called Delayed Flooding with Cumulative Neighborhood (DFCN) [13].

DFCN has thus been compared to those four protocols using some of the performance measurements proposed by Mad_hoc: the number of emissions, the number of redundant receptions of the same message, and the duration of the broadcasting process (makespan).

Results were obtained by varying the density in \([0, 10,000]\) nodes by square kilometer. Since the simulation area is 250,000m\(^2\) (500m x 500m), the number of nodes varies from 0 to 2,500. As shown on figure 5, DFCN exhibits an average number of emissions (the number of emission directly impacts the network bandwidth) which remains much lower than any competitor, no matter the density. Also, the protocol turns out to operate when others do not (when the density is very low).

![Figure 5](image)

Figure 5. The number of emissions carried out by each broadcasting protocol. Only one single node initiates a broadcasting process.

4.2 Broadcasting Algorithm Optimization

Studies on DFCN parameters optimization are have been developed by interfacing Mad_hoc with a multi-objective genetic algorithm. Optimizing a broadcasting strategy can be considered as a multi-objective
problem targeting three goals: minimizing the makespan, maximizing the network coverage, and minimizing the number of transmissions. Five parameters of DFCN are fine-tuned using a new cellular multi-objective genetic algorithm (cMOGA) [2] that computes a Pareto front of solutions to empower a human designer with the ability of choosing the preferred configuration for the network. Three different realistic scenarios implemented by Mad_hoc (see section 1.3.4) are used: mall, city-center and highway scenarios. For computational time reasons (cMOGA uses 25,000 functions evaluations as stopping condition), all those scenarios were optimized in order to be able to run between one and four seconds.

4.3 Simulation of Document Dissemination

DODWAN (Document Dissemination in Wireless Ad hoc Networks) [12, 19] is some Java middleware we developed in order to support the dissemination of structured documents in wireless ad hoc networks, using an epidemic propagation scheme. Mad_hoc was used in this context to provide a simulated version of the DODWAN infrastructure. Particularly, work on progress include that Mad_hoc will be used to simulate a sub-set of the network nodes involved in the DODWAN network. The benefit of this is to test DODWAN over a multi-hop ad hoc network.

This ongoing research is conducted in the context of the Sarah project, which actors are University of Bretagne-Sud, University of Bordeaux I, University of Limoges, and University of Le Havre.

5. Conclusion and future works

This paper presents Mad_hoc, a mobile ad hoc networks simulator enabling the simulation of MobileMANs [9]. Thanks to its hybrid object-oriented/probabilistic model, Mad_hoc makes it possible to simulate large networks (several thousands nodes). It also feature a model for heterogeneous networks and metropolitan mobility models, which are crucial to the investigation of the metropolitan MANETs.

Future works include the development of better broadcasting protocols, of mobility models for the simulation of the dissimilar street configurations present in a city.

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Mad_hoc is currently available for download at:

http://www-lih.univ-lehavre.fr/~hogie/madhoc
References


