Ecological Role Assignments and Mobility Models for Ad Hoc Wireless Networks*

[Extended abstract]

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ABSTRACT

This paper proposes a connection between one of the main research paths in the area of social networks, that is, the computation of role assignments, and one of the main research paths in mobile wireless ad hoc networks, that is, the simulation of node mobility. Motivated by the assumptions that different nodes may move according to different mobility models and that the mobility behavior of a node may vary during time because of changes of its environment, we propose to let the nodes of a network move according to mobility models that are determined by the roles played by the nodes themselves. These roles, in turn, are determined by computing ecological role assignments of the graph induced by the communication network, in which, intuitively, the roles of the nodes in a particular node's neighborhood tend to shape that node into this or that role. In order to implement this approach, we have developed a model mobility simulation framework which allows the user to add new mobility models and to associate to each node of the network a mobility model either manually (by using configuration dialogues) or automatically (by making use of the computation of a role assignment). By making use of this framework, we have then performed some preliminary experimentation of the proposed approach.

Categories and Subject Descriptors

C.4 [**Performance of Systems**]: Modeling techniques; C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*

General Terms

Design, Experimentation, Performance

Keywords

Mobility model, role assignment, ad hoc network

1. INTRODUCTION

A *mobile wireless ad hoc network* (in short, *MANET*) is a computer network in which no pre-existing communication infrastructure exists, communication links are wireless, and nodes are free to move and organize themselves in an arbitrary fashion. These networks are expected to have several applications because of the minimal configuration and the quick deployment they require: natural or human-induced disasters, inter-vehicular communication, law enforcement, military conflicts, and emergency medical situations are just a few examples of application areas in which MANETs are expected to play an important role.

Since the nodes of a MANET are mobile, the network topology may change rapidly and unpredictably over time. It is then important, in order to evaluate the performance of any communication protocol or of any MANET-based application, to be able to accurately simulate the mobility traces of the nodes that will eventually utilize the protocol or the application. For this reason, a great variety of *mobility models* (in short, *MM*s) have been proposed in the literature, which differ according to at least one of the following criteria [4]: the *geographic constraints* that a mobile node has to deal with, the *scale* the model is designed to work for, and *the individuality* which is determined by the node aggregation level of the model. Some examples of mobility models that have been proposed in the past are[1] the random walk

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[1]This list is certainly not exhaustive: our goal, however,

MM [7, 9, 15, 16], the random waypoint MM and its many variations [11], the random direction MM and its many variations [1, 17], the boundless simulation area MM [3], the Gauss-Markov MM [3], the city section MM [3], the exponential correlated random MM [8], the column MM [18], the nomadic community MM [18], the pursue MM [18], the reference point group MM [8], and, more recently, the real-world environment MM [10], the virtual track group MM [19], the ripple MM [5], the clustered MM [13], and the social MM [14].

The goal of this paper is not exactly to propose a new mobility model, but to propose a connection between one of the main research paths in the area of social networks, that is, the computation of role assignments [12], and the simulation of node mobility. In particular, we start from the following two assumptions: *different nodes may move according to different mobility models* and *the mobility behavior of a node may vary during time because of changes of its environment.* On the ground of these two assumptions, we propose to let the nodes of a network move according to mobility models that are determined by the roles played by the nodes themselves. These roles, in turn, are determined by computing an *ecological role assignment* [2] of the graph induced by the communication network: intuitively, if a role assignment is ecological, then the roles of the nodes in a particular node's neighborhood tend to shape that node into this or that role. More formally, an ecological role assignment of a graph is a coloring of the nodes of the graph such that the colors present in a particular node's neighborhood determines the color of that node. The first contribution of this paper is to prove that *almost any graph can be ecologically colored with two and with three colors* and to give a simple algorithm that computes these ecological role assignments: observe that, in the case of the modeling of the mobility of the nodes of a MANET, two or three different roles (that is, two or three different mobility models) seem to be a reasonable number of distinct node behaviors.

In order to actually implement our idea, we have then developed *a model mobility simulation framework* which allows the user to easily add new mobility models and to associate to each node of the MANET a mobility model either manually (by using specific configuration dialogues) or automatically (by making use of the computation of an ecological role assignment). Almost all the mobility models we have previously cited are already implemented in our tool, thus allowing the user to experiment any combination of these models by either assigning them to any subset of the MANET nodes or by assigning two or three of them to the roles played by the MANET nodes. Indeed, we have already performed some preliminary experimentation by using two mobility models previously introduced in the literature and one new model in which nodes are forced to follow a fixed path.

The paper is structured as follows. In Section 2 we describe the algorithms that we use in order to compute the role assignment of a given graph. In Section 3 we briefly describe the simulation tool that we have developed and used in order to obtain the experimental results contained in Section 4.

was just to give a flavor of the huge quantity of MMs that have been proposed in the literature and of how important the mobility simulation topic is within the MANET research area.

2. THE COLORING ALGORITHM

As we already said in the introduction, an ecological role assignment of a graph is a coloring of the nodes of the graph such that the colors present in a particular node's neighborhood determines the color of that node.

Definition 1. Given a graph $G = (V, E)$ and an integer k with $1 \leq k \leq |V|$, a k-coloring $r : V \to \{1, \ldots, k\}$ of G is *ecological* if, for any $u, v \in V$,

$$r(N(u)) = r(N(v)) \Rightarrow r(u) = r(v) \tag{1}$$

where, for any $u \in V$, $N(u)$ denotes the neighborhood of u in G.

Observe that any graph can be ecologically colored with one color, since in this case the right part of (1) is always satisfied: however, it is not true that any graph can be ecologically colored with n colors, where n is the number of nodes of the graph. For example, it is easy to verify that the path P formed by the three nodes p_0, p_1, and p_2 cannot be ecologically colored with three colors, since, for any coloring r, $r(N(p_0)) = r(N(p_2)) = \{r(p_1)\}$ and, hence, p_0 and p_2 must be colored with the same color. The existence of an ecological coloring with k colors is analyzed in [6] for any value of k, with $2 \leq k \leq n$.

In the case of modeling the mobility pattern of a MANET, we can reasonably assume that the number of roles played by the mobile entities is small: in particular, we restrict ourselves to two or three roles. The goal of this section is to describe a simple algorithm which can be used in order to compute an ecological 2- and 3-coloring of almost any graph.

THEOREM 1. *Any graph with at least two nodes which is not an independent set can be ecologically colored with two colors.*

PROOF. Let $G = (V, E)$ be a graph with $|V| > 1$ and let I be a maximal independent set of G. Let us then consider the graph G_I induced by the set $V - I$ (which is not empty since G contains at least one edge): this graph can be ecologically colored with color 2 (since any graph can be colored with one color). Moreover, each node of G_I is adjacent to at least one node of I (since I is maximal): hence, by coloring all nodes in I with color 1 we obtain an ecological coloring of G. Indeed, for any node $u \in I$, $r(N(u)) = \{2\} \wedge r(u) = 1$ while, for any node $u \notin I$, $(r(N(u)) = \{1\} \vee r(N(u)) = \{1, 2\}) \wedge r(u) = 2$. □

We now prove that, by iterating the computation of maximal independent sets, we can obtain ecological colorings of almost any graph with three colors.

LEMMA 1. *Any connected bipartite graph which is not complete can be ecologically colored with three colors.*

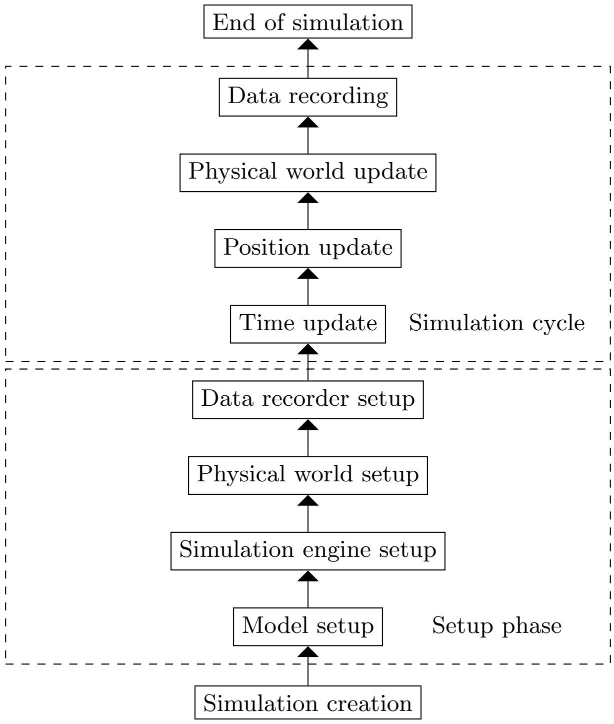

Figure 1: The sequence of events within a simulation.

PROOF. Let $G = (V_1 \cup V_2, E)$ be a connected bipartite graph such that there exist two nodes $u \in V_1$ and $v \in V_2$ which are not adjacent, and let I be an arbitrary maximal independent set containing u and v: moreover, let $I_1 = I \cap V_1$, $I_2 = I \cap V_2$, $W_1 = V_1 - I$, and $W_2 = V_2 - I$. Since I is maximal, any node in W_1 must be adjacent to at least one node in I_2, while any node in W_2 must be adjacent to at least one node in I_1. Moreover, since G is connected there must exist two adjacent nodes $x \in W_1$ and $y \in W_2$: let X_1 (respectively, X_2) be the set of nodes in W_1 (respectively, W_2) which are adjacent to at least one node in W_2 (respectively, W_1). By coloring all nodes in I with color 1, all nodes in $X_1 \cup X_2$ with color 2, and all other nodes with color 3, we obtain an ecological coloring of G: indeed, for any node $u \in I$,

$$\Big(r\big(N(u)\big) = \{2\} \vee r\big(N(u)\big) = \{3\} \vee r\big(N(u)\big) = \{2,3\}\Big)$$

while, for any node $u \in X_1 \cup X_2$, $r\big(N(u)\big) = \{1, 2\}$ and, for any other node u, $r\big(N(u)\big) = \{1\}$. $\square$

As opposed to the previous lemma, a complete bipartite graph cannot be ecologically colored with three colors, since each node of one partition has the same neighborhood of the other nodes of the same partition: hence, all nodes of the same partition must be colored with the same color and, since there are only two partitions, we can not use the third color. The next result shows that the complete bipartite graphs are the only connected ones which cannot be ecologically colored with three colors.

THEOREM 2. *Any connected graph with at least 3 nodes which is not complete bipartite can be ecologically colored with three colors.*

PROOF. Let $G = (V, E)$ be a graph with $|V| > 2$ and let I be an arbitrary maximal independent set of G. Since G is connected and it is not complete bipartite, $|V - I| \geq 2$: let G_I be the graph induced by the set $V - I$. If G_I is an independent set, then G is a connected bipartite graph which is not complete, and from Lemma 1 it follows that G can be ecologically colored with three colors. Otherwise (that is, if G_I is not an independent set), from Theorem 1 it follows that G_I can be ecologically colored with colors 2 and 3: let r_I denote this ecological coloring. Moreover, each node of G_I is adjacent to at least one node of I (since I is maximal): hence, by coloring all nodes in I with color 1 we obtain an ecological coloring r of G. Indeed, for any node $u \in I$, $r(u) = 1$ and

$$r\big(N(u)\big) = \{2\} \vee r\big(N(u)\big) = \{3\} \vee r\big(N(u)\big) = \{2,3\}$$

while, for any node $u \notin I$, $r\big(N(u)\big) = r_I\big(N(u)\big) \cup \{1\}$: since r_I is an ecological coloring of G_I, it follows that r is an ecological coloring of G. $\square$

In order to simplify and to accelerate the computation of the role assignments, we actually make use of the following approximation of the two previously described algorithms (even though this approximation does not guarantee that the resulting role assignment is ecological). Given a graph $G = (V, E)$ and given $k \in \{2, 3\}$, we first compute a maximal independent set I_1 of G: if $k = 2$, then we color all the nodes in I_1 and $V - I_1$ with the colors 1 and 2, respectively. Otherwise (that is, if $k = 3$), we compute a maximal independent set I_2 of the graph induced by $V - I_1$, and we finally color all the nodes in I_1, I_2, and $V - (I_1 \cup I_2)$ with the colors 1, 2, and 3, respectively.

3. THE SIMULATION TOOL

Our tool allows the user to simulate the movement of a set of nodes within an environment which may contain physical obstacles. The tool includes the implementation of a signal propagation model in order to take into account the signal fading as it propagates through a physical obstacle: this feature is necessary in order to realistically emulate the communication network and, hence, correctly compute a role assignment. The nodes can be physical objects and they can move according to different mobility patterns in a pairwise independent way: the tool manages the collisions between pair of nodes and between the nodes and the physical obstacles present in the environment.

The sequence of events which happen during a simulation is depicted in Figure 1. In particular, the simulation creation phase allows the user to specify the mobility models which have to be used while generating and managing the nodes, the simulation time, the scenario within which the nodes move, and the data recorders which have to be used during the simulation.

Once the simulation has been inizitialized, the mobility models, the simulation engine, the physical world simulator, and the data recorders have to be setup. Successively, the simulation can start. During each simulation cycle, the simulation time is updated, the simulation engine let each node "think" about its next position, the physical world simulator applies these new positions and manages the collisions, and the data recorders store the data concerning this simulation cycle. Moreover, a simulation management window allows the user to see all the information concerning the state of the simulation, such as the current time and the current simulation cycle.

At the end of the simulation, the data stored by the data recorders can be used, for example, either as mobility traces for the simulation of a specific communication protocol or of a specific MANET application, or for visualizing the movement of the nodes during the entire simulation.

Observe that, in order to implement the role assignment mechanism, it is sufficient to define a mobility "meta-model" that is assigned to all the nodes: this model, before letting the single nodes think about their new positions, decides whether the current role assignment has to be changed and, in this case, computes the new role assignment corresponding to the current communication network, and assigns to each node the mobility model associated to its role.

4. SOME EXPERIMENTAL RESULTS

It should be clear that any experimentation based on our approach strongly depends on which mobility model is associated to any of the node roles. For example, we have experimented that if nodes with different roles all move according to the random walk model whose parameters depend on the role, then one role, that is, the last one computed by the algorithm, tends to disappear, which implies that the communication network tends to become basically formed by two huge maximal independent sets.

In Figure 2, instead, some experimental results are shown according to the following simulation framework.

- The number of nodes is 100 and the number of roles is 3.
- The simulation time is 60 seconds, the simulation step is 0.01 seconds, and the role assignment is computed every 5 seconds.
- The simulation environment is 600×600 square and the communication range of the nodes varies between 1, 5, 10 and 20.
- The first role computed by the algorithm is associated to the pursue group mobility model [18], the second role is associated to the random walk model, and the third role is associated to a model in which each node follows a fixed path through a fixed set of hot spots. The combination of these three models might represent, in our opinion, the mobility pattern of people walking within a touristic city, like Florence or Rome.

From the experiments, we have extracted information concerning the connectivity degree of the communication network (see the upper left part of the figure), the average number of edges incident to a node (see the upper right part of the figure), and, for each role, the number of nodes with that role and their average number of incident edges (see the remaining parts of the figure).

5. CONCLUSIONS

In this paper, we have proposed a simulation model of mobile entities based on the analysis of social networks. We might also say that our approach produces a new group mobility model, but, differently from other models of this kind, the composition of each group is not static and changes over time: indeed, the group a node belongs to depends on its environment, that is, on the groups its neighbors belong to.

The experimental results, that have been produced by means of the simulation tool we have developed, show how the composition of the groups strongly depends on the mobility model which is associated with each group. As expected, for any such association, the topology of the resulting communication network depends on the communication range of the nodes.

Our next goals will be to perform a more extensive experimentation by considering different combinations of all the mobility models that are currently implemented in our simulation tool, and to compare our approach with other group mobility models that have been previously proposed in the literature (in particular it should be interesting to compare our approach with the one proposed in [14]).

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Figure 2: Experimental results with three different mobility models.

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