A Group Mobility Model Based on Nodes' Attraction for Next Generation Wireless Networks

Leonardo Badia
IMT Lucca, Institute for Advanced Studies
via San Micheletto 3
55100 – Lucca, Italy
bdalrd@unife.it

Nicola Bui
Dipartimento di Ingegneria, Università di Ferrara
via Saragat 1, blocco A
44100 – Ferrara, Italy
buincl@unife.it

ABSTRACT

This paper proposes a novel mobility model aiming at capturing the grouped mobility behavior of the users of a wireless network. The description and possibly the exploitation of similar mobility patterns of users, moving in a correlated fashion and originating groups, is an important challenge for future generation networks. In fact, a correct understanding of this phenomenon can be applied in order to gain cross-layer knowledge, therefore improving the management of the network by exploiting the presence of mobile groups.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – *Network communications, Wireless communication*

General Terms

Algorithms, Performance, Design.

Keywords

Mobility Models, Mobility Groups, Simulation Tools.

1. INTRODUCTION

The description of the mobility patterns of wireless terminals is an important aspect for radio communication networks, and obtaining simple but effective models able to capture the most important characteristics of mobile users is an open issue [1].

The exploitation of correlations and similarities can be useful in order to improve the network performance. Even more, the aggregation of the mobility patterns for many users can be advantageous in order to predict proper management and provisioning of radio resources, as for example in a group handover case [2].

Mobility'06, October 25–27, 2006, Bangkok, Thailand.

Finally, the mobility of the users in a correlated fashion, e.g., around an attraction point, can lead to a partial centralization of network operation, which is another aspect where network performance can be improved [3].

In the literature, several models can be found, which try to capture the behavior of groups of mobile terminals in heterogeneous environments [1,4,5]. A detailed representation of users' mobility is necessary for the design of good simulation tools and the correct evaluation of protocol performance. Detailed surveys on mobility models can be found in [4] and [6]. Often, mobility models try to imitate real mobility patterns, as well as to analyze the properties of the mobile users from a statistical point of view.

The simplest case of mobility model considers users moving with randomized patterns and independently of each other, obtaining the so called entity mobility models [4]. This category includes, for example, the "Random way-point" and the "Random Walk" models [1]. More advanced mobility models consider the additional correlation of the users which causes aggregation of the movements, i.e., group mobility. These models include for example the Reference Point Group Model (RPGM) [7] and the Structured Group Mobility Model (SGMM) [8].

The need for grouped mobility models becomes therefore important in order to have both a realistic characterization of positioning and mobility of wireless users, and also to test algorithms aimed at improving network management operation when users move in a grouped fashion.

In this paper, we aim at introducing a mobility model which can easily account for grouped mobility and is not simply yet another model for wireless users. It offers in fact the following advantages. First of all, it is easily adaptable to different scenarios, as will be shown in the following. This is because the model splits the movement of the users into two separate components, which account for different aspects of the movement. In particular, we consider the users' movement as derived from the superimposition of a *drift movement* of group of nodes which tend to follow one of them playing the role of the group leader and a *random movement* which can be determined by any generic model and can be regarded as a noise applied to the drift component. This also offer the additional advantage that, on the one hand, different mobility model can be used as random component within the same framework, and on the other hand also different choices of the drift component can be applied in order to obtain different characterization of the movement. This realizes a very general framework, which is able to capture different motion scenarios. Finally, as we will show in detail throughout the paper, the generality of the model is coupled with an easy setup of the parameters, which have a very intuitive meaning. This can be useful for simulation tools where it is often desirable to control the dependence of the results on a certain mobility parameter, while the others are fixed.

The rest of the paper is organized as follows: in Section 2 we outline the model from a very general perspective. In Section 3, we give an example of application of the model for what concerns the grouped mobility to a simple scenario where the basic node mobility, to which the aggregation is superimposed, is represented by a tunable correlated linear mobility with random rotations. In Section 4 we evaluate numerically this instance of the model and finally in Section 5 we conclude the paper.

2. MODEL OUTLINE

As the network complexity of future generation wireless systems increases, the need for detailed simulation platforms is growing at the same time. Nowadays, wireless terminals are capable to integrate multiple technologies in the same chipset and they offer a plethora of services and possibilities of access [9]. Moreover, the penetration of wireless technologies has become widespread, so that it is frequent to find not only single users exploiting wireless access, but also group of users enjoying similar services at the same time, e.g., multiplayer games or multicast communication [3].

At the same time, the simulation tools which have been developed during last years have become very accurate for what concerns physical propagation and collection of real data [10]. However, it is also important that they capture high level characteristics, in particular terminal aggregation, which have a strong impact on the overall performance [11].

For this reason, in this paper we aim at introducing a general mobility framework, where we particularly aim at capturing the aggregation phenomena which occur in wireless networks. The main advantage of our proposed model is that it consists of a very general part, where any preferred mobility characterization can be framed, and an original contribution where we focus on group of terminals in order to obtain aggregate mobility behavior.

In the following, we outline the basic characteristics of the model. We assume that the nodes are attracting one each other, according to a numerical value characteristic of each node describing its “charisma,” which can be also thought as a sort of mass or electrical charge, i.e., a parameter intrinsically quantifying the property of the node of attracting others.

A relationship of leadership is also defined among the nodes, so that each node possesses a unique leader, but a given node can be the leader of several nodes, called followers. Nodes' movements consist of two terms: a drift movement which tend to follow the leader and random movement which can be determined by any of the available models for independent mobility modeling proposed in the literature, which can be regarded as a noise superimposed to the drift component.

In the following, we describe the first term in detail. From a high level perspective, the model operates by considering a time-sampling of sufficiently fine granularity. At each time slot, nodes' movements are evaluated and the position updated. We consider the movement of each node to be the vector sum of two components. The first one is a randomly generated movement, whereas the second is obtained as an attraction movement toward a leader. This happens by considering a properly defined *attraction field*, where if C_l and C_f are the charge values associated with leader and follower, respectively, we have that:

$$\vec{F}_a = \gamma \frac{C_l C_f}{d^\alpha} \vec{u}_a \quad (1)$$

In the above Equation, α and γ are constant parameters used to tune the intensity of the attraction field. In particular, α is very important for what concerns the setup of the distance between nodes. As a practical guideline, α should not be greater than the value of the Coulomb law, i.e., 2. Reasonable values are between 0.3 and 1.2. $\vec{F}_a$ is the attraction force experienced along the axis connecting two nodes separated by d meters and $\vec{u}_a$ is the unit vector denoting this axis. By considering particles of unit mass one can get to the following expression for the attraction velocity:

$$\vec{v}_a(t) = \beta(t) \frac{C_l C_f}{d^\alpha} \vec{u}_a \quad (2)$$

where $\vec{v}_a(t)$ is the attraction speed at time t along the direction connecting the two nodes (follower and leader). $\beta(t)$ is the module of the attraction speed at a distance d = 1 m, which is calculated, at every time step (the speed is recomputed every Δt seconds), by means of the following discrete time filter:

$$\beta(t_k = t_{k-1} + \Delta t) = (1 - \zeta_a)\beta(t_{k-1}) + \zeta_a s_{a,k} \quad (3)$$

where ζ_a in [0,1] is a tunable variable which is the coefficient of the filter, whereas $s_{a,k}$ is a sample from a Gaussian random variable with mean s_{am} and standard deviation s_{av}. The speed vector for a given follower at time t is calculated as:

$$\vec{v}(t) = \vec{v}_i(t) + \vec{v}_a(t) \quad (4)$$

where $\vec{v}(t)$, i.e., the speed at the generic time t, is obtained as the vector sum of two contributions, namely the speed term $\vec{v}_a(t)$ due to the attraction taking place between the follower and the leader, which lies along $\vec{u}_a$, i.e., the direction connecting the two nodes, and the speed term $\vec{v}_i(t)$, corresponding to the speed associated with an independent mobility pattern, which is superimposed to the attractive behavior.

The last term $\vec{v}_i(t)$ can be obtained according to any entity mobility model. In the next section, we will discuss an exemplificative possibility for $\vec{v}_i(t)$ in order to give validation results. The term $\vec{v}_a(t)$ is the one which in practice implement our model, i.e., characterizes the follower-leader attraction by forcing the followers to move in the direction of their leader. As a result of our mobility modeling approach, each node tends to follow its own leader. Leaders move independently according to any entity mobility model and without being attracted by their followers. In their case the above equation for the calculation of $\vec{v}(t)$ still applies by letting $\vec{v}_a(t)$ equal to 0. Finally $\vec{v}(t)$ is updated every Δt seconds where Δt is the time unit. Another sampling rule which follows more or less the same rationale can also be used for updating $\vec{v}_i(t)$, as will be explained in the following section.

In particular, observe that the group mobility model proposed here is very general as there is no need to define reference points for the followers. Moreover, group movements can be adapted to very different behaviors by appropriately setting the parameters of the attraction field $\vec{F}_a$. Other factors, such as the presence of streets, obstacles, minimum and/or maximum distances between leader and its followers can be accounted as well through straightforward modification of the force field and by limiting the obtained mobility vectors.

3. AN EXAMPLE OF INDEPENDENT MOBILITY COMPONENT.

In this section, we outline an example of mobility model that we could consider to track independent movements, accounted for in the term $\vec{v}_i(t)$. This part is where we have a higher degree of freedom, since the modeling of the grouped mobility component can be applied to other kinds of mobility as well. The background idea in the model we have chosen is that in everyday life, people tend to move with a certain memory [1] which depend on their mobility pattern, so that they keep more or less a constant movement as long as some external factors intervene, e.g., an obstacle or a decision to turn in another direction force them to change the value or the direction of their speed.

On the other hand, to have a suitable underlying mobility coupled with our proposed attraction framework, we need a sufficiently tunable module where different mobility patterns can be set, e.g., linear vs. rotational mobility, different durations of the motion memory and so on.

To account for all these issues, we assume that nodes move by keeping the value of $\vec{v}_i(t)$ as constant within subsequent sampling instants. We consider that sampling instants can even be not equally spaced. We now describe a possibility to obtain also this effect. Every time a new sampling time τ_k occurs, $\vec{v}_i(t)$ is updated by performing the following actions: first of all, a new value for $\vec{v}_i(t)$, the module of the velocity, is calculated by means of the discrete time low pass filtering:

$$|\vec{v}_i(\tau_k)| = (1-\zeta_i)|\vec{v}_i(\tau_{k-1})| + \zeta_i s_{i,k} \quad (5)$$

where ζ_i in [0,1] is the coefficient of the filter, whereas s_k is an independent sample chosen from a Gaussian random variable with mean s_{im} and standard deviation s_{iv}. These values are parameters which can be set up properly in order to determine the instant value of the speed. The angle associated with the mobility vector is given by:

$$\vartheta_i(\tau_k) = \vartheta_i(\tau_{k-1}) + \Delta\vartheta_i(\tau_k) \quad (6)$$

where $\vartheta_i(\tau_{k-1})$ is the angle associated with $\vec{v}_i(t)$ at the previous step, i.e., step k–1, and the variation $\Delta\vartheta_i(\tau_k)$ is drawn from a uniform distribution in [-ϑ_{max} /2, ϑ_{max} /2], where ϑ_{max} is a constant value determined a priori in [-π,π], which imposes a linear vs. rotational behavior. To describe the update memory, sampling intervals occur every M+$U(K)$ time units of length Δt, where $U(K)$ is drawn from a uniform discrete distribution in ($-K$, $-K+1$,…, $K-1$, K). Hence:

$$\tau_k = \tau_{k-1} + (M + U(K))\Delta t \quad (7)$$

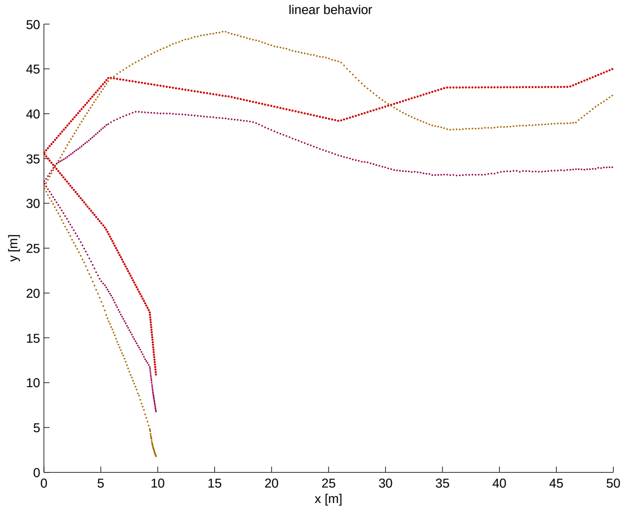

Fig. 1 – A group of three users moving with pseudo-linear independent mobility together with attraction toward the leader (red trace).

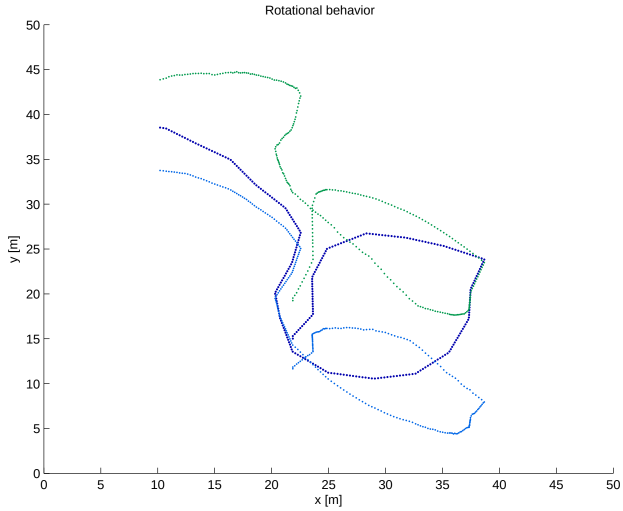

Fig. 2 – A group of three users moving with pseudo-rotational independent mobility together with attraction toward the leader (dark blue trace).

This model is very tunable and allow for pseudo-linear and pseudo-rotational mobility, as is visible from Fig. 1 and Fig. 2, respectively, where the resulting traces for a group of three users moving with group mobility are plotted. The pseudo linear movement is obtained by choosing a small value of ϑ_{max}, in this case ϑ_{max} = π/3, whereas the rotational behavior corresponds to ϑ_{max} = π. Intermediate kinds of movement are of course possible. Note also that it is possible, by properly setting the attraction between the users of each group and their leader, to tune the distance they keep with the leader motion. At the same time, it is also possible to represent different memory levels in the independent term of the movement and in the attraction component, by properly tuning M and/or the filters' coefficients ζ_a and ζ_i.

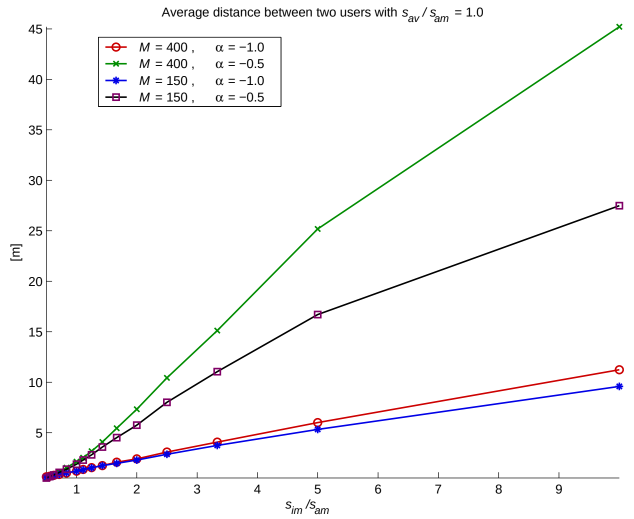

Fig. 3 – Average distance between two common nodes as a function of the ratio s_{im}/s_{am} for different values of process memory M and attraction charge α.

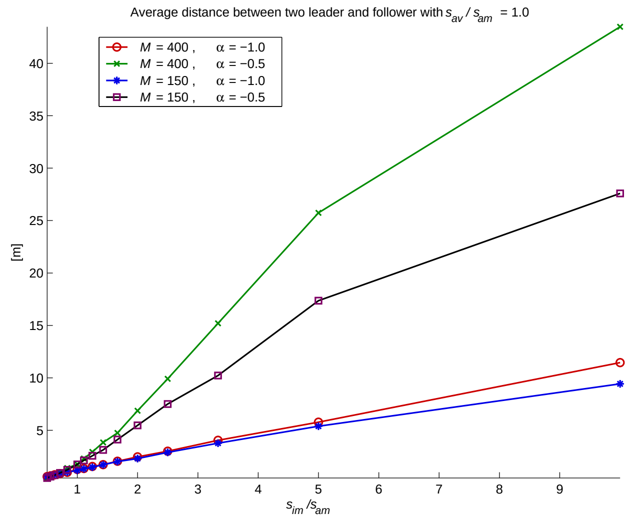

Fig. 4 – Average distance between a node and its leader as a function of the ratio s_{im}/s_{am} for different values of process memory M and attraction charge α.

4. NUMERICAL EXPLORATION.

In this section, we evaluate through a simulative benchmark some typical parameters of users' mobility obtained through our model. The goal is to show that our model allows a simple set up of certain high level values through a proper choice of the attraction and mobility memory parameters.

We consider an area of 100 × 100 m^2 where users move according to our mobility model. To avoid border effect, we assume the region to have spherical geometry (i.e., nodes exiting at one side re-enter from the opposite side). However, unless the average speed of the nodes is very high, this does not impact very much on the performance, i.e., other kinds of geometry we have tested (e.g., with elastic or hard walls, or thoroidal geometry) present results which do not differ significantly from the spherical geometry.

First of all, we investigate the mobility model by evaluating the inter-node distance. Unless differently specify, we use the following default choices of parameters: s_{am} = 1 km/h, s_{av} = 0.01 s_{am}, s_{iv} = 0.01 s_{im}, which can describe a pedestrian mobility pattern with quasi constant speed. The value $\vartheta_{\max}$ is set to 0.3π, leading to a pseudo linear mobility behavior. The value of M can be either 150 or 400, with K = 25 and Δt = 0.1 s. An interesting evaluation is obtained by changing s_{im}, i.e., the average absolute value of the independent mobility component $\vec{v}_i(t)$.

We report the obtained results in Figs. 1 and 2, where we plot the average inter-node distance and the average distance between a mobility group leader and its followers, respectively. We consider two cases of mild and stronger attraction, where α equals 0.5 and 1.0, respectively. From these figures, we see that when the module of α is larger the average distances grows linearly with s_{im} / s_{am}. This is a useful result, which establishes a practical relationship between the model speeds and the distance properties of the group mobility pattern, and is therefore very useful for a quick network setup in a simulation campaign, where the average distance between nodes may be an interesting parameter to vary.

When α is smaller, the group mobility becomes more relaxed and the model realizes movements of the users characterized by a higher freedom to float around the leader. Nevertheless, it is emphasized that when the independent component of the movement does not correspond to a very fast motion (relatively lower values of the ratio s_{im}/s_{am}), the same conclusion holds, i.e., the average inter-node distance grows approximately linearly.

For wireless networks, it becomes often important to check connectivity properties, which depend on the radio coverage. For simplicity, let us assume a simple radio propagation model, where a fixed coverage radius d_0 is assumed, so that any two users can communicate with each other if their reciprocal distance d is less than or equal to d_0. We can adopt this approach, which neglects for example the impact of the specific MAC where collisions might arise, if we are interested in estimating the plain connectivity performance of the mobility model. However, it is possible to perform more accurate evaluations by introducing a proper MAC description [12], which is however outside of the scope of the present paper.

For the coverage analysis, it is useful to check whether the average distance of two nodes belonging to the same mobility group falls below a given threshold, so that they can be considered, under this simple propagation model, in coverage range of each other.

In the following, we investigate the group members radio coverage metric. For the same mobility parameters as above, we take s_{im}/s_{am} as the independent variable again and we compute the coverage ratio, which is defined as the ratio of in range users with respect to the total number of users in the mobility group.

We consider in this evaluation possible values for the radio range of a typical piconet, e.g., a Bluetooth PAN [13]. This is coherent with our choice of representing a pseudo-linear pedestrian mobility pattern. Note however that similar evaluation can be applied to different radio ranges as well.

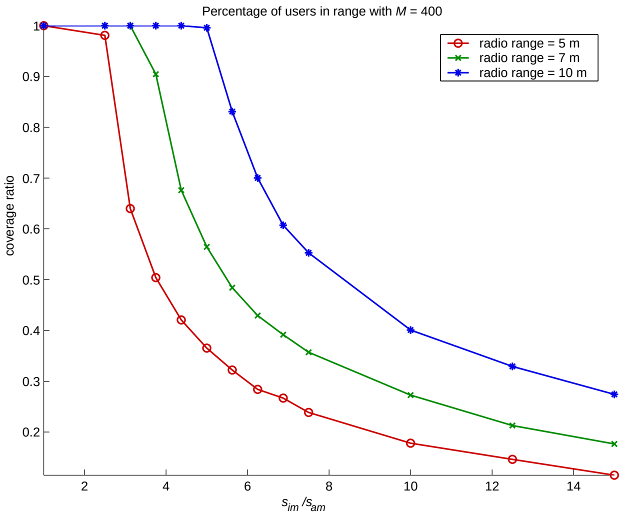

Fig. 5 – Coverage ratio among nodes of the same group as a function of the ratio s_{im}/s_{am} for M = 400 and α = 0.5.

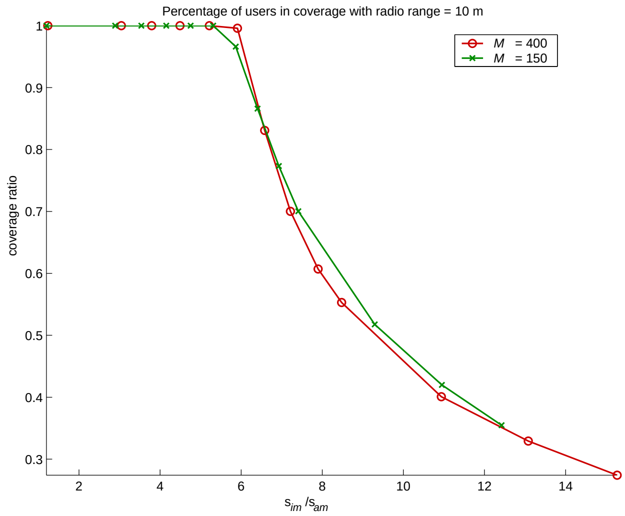

Fig. 7 – Coverage ratio among nodes of the same group as a function of the ratio s_{im}/s_{am} for d_0 = 10 m and α = 0.5.

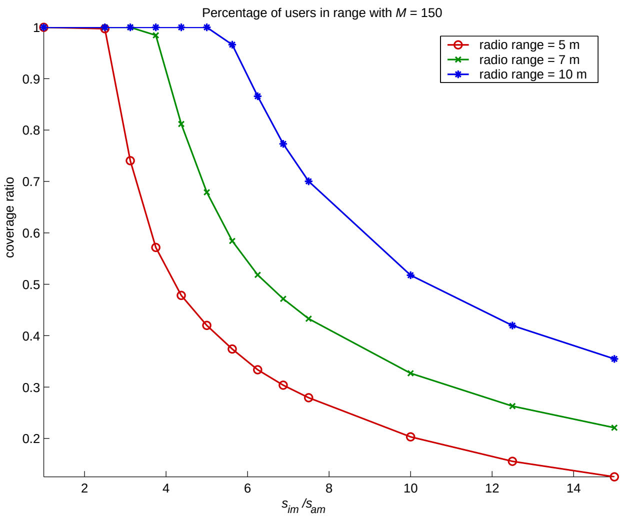

Fig. 6 – Coverage ratio among nodes of the same group as a function of the ratio s_{im}/s_{am} for M = 150 and α = 0.5.

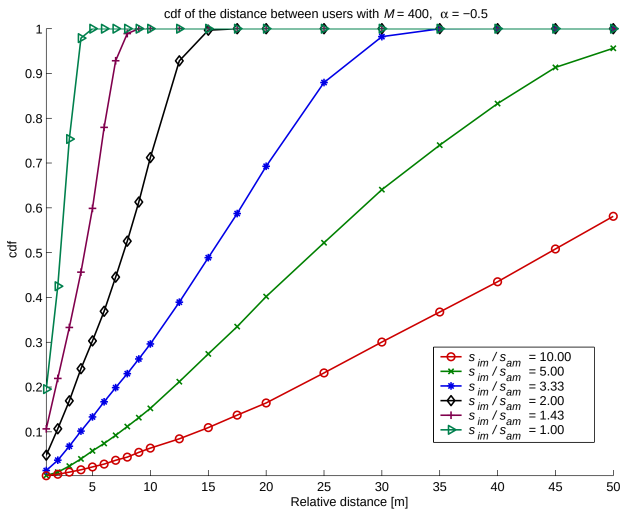

Fig. 8 – Cumulative distribution function of the distance between nodes as a function of the average group size.

We evaluate the performance of the coverage ratio for the mobility groups for the attraction field exponent α set to 0.5. This means that nodes are floating almost freely with a mild attraction to the leader. This is the most interesting case, where there is high sensitivity on the nodes' speed, since, as visible from Figs. 3–4, the average distance between nodes of the same group can be significant. Hence, whereas for the case where $\alpha = 1.0$ the group is definitely more compact, in this case of weaker attraction between nodes can be meaningful to investigate how many of them stay on average within radio coverage. In this scenario, we plot the coverage ratio for the radio range radius d_0 equal to 5, 7 and 10 meters and for the system memory M equal to 400 and 150, respectively, in Figs. 5 and 6.

As can be easily derived intuitively, the larger the coverage radius, the higher the coverage ratio. Moreover, as the average value of $\vec{v}_i(t)$ increases, also the average inter node distance increases, and therefore the coverage within the mobility group decreases. However, there is still a certain amount of users which are connected, since users are normally floating *around* the leader.

Thus, if the radio coverage is large enough, there is a fraction of users which are one-hop connected, even though the independent component of the speed is very high. Note that the connectivity could be further increased through multi-hop within the group [3].

Moreover, we observe that even though the two mobility scenarios (with different values of M) above are different in terms of average inter-node distance, as visible from the previous results, they lead to similar coverage metrics. This results is further emphasized in Fig. 7 where we compare the two coverage ratio traces for d_0 = 10 m. This means that a higher mobility memory increases only the distance for the nodes further from the leader, but keeps more or less constant the percentage of nodes that are in coverage, which is important to know, in the choice of the mobility parameter M, that its effect determine the shape of the mobility pattern but is not so relevant for the average groups size.

Finally, in Fig. 8 we expand the rationale described by Figs. 5 and 6 in the cumulative distribution function (cdf) of the distance between nodes for the case $M = 400$, $\alpha = 0.5$ and different choices of the ratio s_{im} / s_{am}. As discussed previously, the average value of the distance between nodes is not always representative of the entire statistics of every order, which might be hence interesting to be characterized through the cdf. In particular, the plot traces reported in the figure might be then useful for example to evaluate the amplitude of the oscillations in the group size or even higher order statistics of the average inter-node distance obtained by using our model.

Similar figures of this kind can be obtained by properly tuning the mobility parameters in an entirely transparent manner. This might be therefore a practical guideline first of all to characterize some specific outcome, such as the inter-node distance in the mobility group, but also especially to be employed within a simulation framework in order to tune different mobility values through the parameters of our mobility model.

5. CONCLUSIONS.

Improving the description and characterization of mobility patterns and connectivity relationships between wireless terminals is one of the many challenges to be faced in future generation wireless networks.

In this paper, we presented a mobility model which is able to capture different aspects of users' movement characteristics, most notably the aggregated mobility in group of users, obtained by introducing a proper *attraction field* which determines, regulates and control the intensity of the attraction between nodes. Note that this framework do not rely on a particular choice of the underlying independent component of the mobility of each node, which might be identified with any existing model and also adapted to a particular case study under investigation.

The model presents several tunable parts, which have been discussed through the paper. In this way, we showed how a practical guideline may be obtained to proper set up the equations. We believe that such a model can be helpful to give a realistic representation and characterization of future generation mobile networks.

6. REFERENCES.

[1] M. Zonoozi and P. Dassanayake, "User mobility modeling and characterization of mobility patterns," *IEEE Journal on Selected Areas in Communications*, vol. 15, pp. 1239–1252, 1997.

[2] Q. Huang, C. Julien, and G.-C. Roman, "Relying on safe distance to achieve strong partitionable group membership in ad hoc networks," *IEEE Transactions on Mobile Computing*, vol. 3, no. 2, pp. 192–205, 2004.

[3] P. Mohapatra, C. Gui, and J. Li, "Group communications in mobile ad hoc networks," *IEEE Computer Magazine*, vol. 37, no. 2, pp. 52–59, 2004.

[4] T. Camp, J. Boleng, and V. Davies, "A survey of mobility models for ad hoc network research," *Wiley Wireless Communications & Mobile Computing (WCMC)*, vol. 2, no. 5, pp. 483–502, Aug. 2002.

[5] C. Bettstetter, "Smooth is better than sharp: a random mobility model for simulation of wireless networks," in *Proceedings of ACM MSWiM*, 2001, Rome, Italy.

[6] Q. Zheng, X. Hong, and S. Ray, "Recent advances in mobility modeling for mobile ad hoc network research," in *Proceedings of the 42nd ACM annual Southeast regional conference*, 2004.

[7] B. Zhou, K. Xu, and M. Gerla, "Group and swarm mobility models for ad hoc network scenarios using virtual tracks," in *Proceedings IEEE MILCOM*, vol. 1, 2004, pp. 289–294.

[8] K. Blakely and B. Lowekamp, "A structured group mobility model for the simulation of mobile ad hoc networks," in *Proceedings of ACM MobiWac*, 2004, Philadelphia, Pennsylvania, US.

[9] A. Furuskär and J. Zander, "Multiservice allocation for multiaccess wireless systems," *IEEE Trans. on Wireless Commun.*, vol. 4, no. 1, pp. 174–184, 2005.

[10] P. Daniele, M. Frullone, K. Heiska, G. Riva, C. Carciofi, "Investigation of adaptive 3D microcellular prediction tools starting from real measurements", *Proceedings of ICUPC*, Cambridge, Massachusetts, 1996, pp. 468 – 472.

[11] S.Hanemann, R. Jansen, and B. Freisleben, "Reducing packet transmissions in ad hoc routing protocols by adaptive neighbour discovery," in *Proceedings of International Conference on Wireless Networks*, 2003, pp. 369–375.

[12] P. Popovski, F.H.P. Fitzek, H. Yomo, T.K. Madsen, R. Prasad, and N.J. Vej, "MAC-layer approach for cluster-based aggregation in sensor networks," in *Proceedings of International Workshop on Wireless Ad-Hoc Networks (IWWAN)*, 2004, pp. 89–93.

[13] B. A. Miller and C. Bisdikian, *Bluetooth revealed: The Insider's Guide to an Open Specification for Global Wireless Communications*. Prentice Hall, 2000.