Grcmob: a Group Mobility Pattern Generator to Evaluate Mobile Ad Hoc Networks Performance

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Abstract. We present an analysis of the behavior of a routing protocol when group mobility is involved. We concentrate on group mobility because there is a growing attention on the development and evaluation of MANET's approach applied to *personal area networks* (PANs), especially based on Bluetooth technology.
We propose four different group mobility models and describe a mobility pattern generator called `grcmob` to be used with the ns-2 simulator. We compare the behavior of a classical reactive routing protocol, the *Dynamic Source Routing* (DSR) protocol and we perform a thorough evaluation of its behavior using as a reference the behavior obtained with the random waypoint mobility model.
We observe the high variability of the results and the need to know exactly the behavior of the system and the impossibility to define a unique proposal which is general to whatever environment. We make evident that also the mix of inter- and intra-group communication has a strong impact on the routing protocol performance and should therefore be taken into consideration when tuning or designing a routing protocol. Finally, we demonstrate that the presence of groups forces the network topology to be more sparse and therefore the probability of network partitions and node disconnections grows.

1 Introduction

Mobile ad hoc networks (MANETs) are an example of mobile wireless networks that do not require any fixed infrastructure, which means that their topologies can vary randomly and at unpredictable times. The *Internet Engineering Task Force* (IETF) MANET working group [1] proposed various routing protocols for *ad hoc* networks during the past few years. The evaluation of most of these proposals has been performed with the aid of various network simulators. Most of these tools, such as the ns-2 [2] or the GloMoSim [3], make use of synthetic models for mobility and data patterns.

However, the general problem of modelling the behavior of the nodes belonging to a mobile network has not a unique and straightforward solution. Mobility patterns depend on various factors like the physical environment, the user objectives, and the user inter-dependencies. Hong et al., [4] showed that these models can have a great effect upon the results of the simulation, and thus, on the evaluation of these protocols. In [5] a survey of the existing mobility models is presented.

The mobility models that are commonly used to simulate MANETs can be classified into two categories: individual-based and group-based. An individual-based model describes node mobility independently of any other nodes. With group-based mobility models, individual nodes movement is depended on the movement of close-by nodes.

The objective of this work is to show the impact of group mobility on the behavior of a routing protocol and to present the critical factors that must be taken into consideration when optimizing the behavior or in general the design of a routing protocol for MANETs. We compare the results with the classic *Random Waypoint* [6] model without groups to simply provide a reference to better understand the obtained results. We concentrate on group mobility because there is a growing attention on the development and evaluation of the MANETs approach applied to *personal area networks* (PANs), especially based on Bluetooth technology [7]; consider for example the work of Gerla et al., [8]. PANs exploit the concept of "piconets", that is a very small-area network, normally of up to 8 nodes, where a dedicate node is the "master" inside the topology. Piconets can be joined together to form "scatternets". This types of networks emphasize the group-behavior of the network and therefore reinforce the need for more dedicated mobility models.

We describe four different group mobility models: the *Random Waypoint Group Mobility Model* (RWG), the *Random Direction Group Mobility Model* (RDG), the *Manhattan Group Mobility Model* (MHG) and the *Sequential Group Mobility Model* (SQG). The RWG model extends the classic random waypoint model applying mobility to a subset of close-by nodes at a time. While with the RWG model a group destination is normally inside the movement area, with the RDG model we stretch the final destination to a border of the movement area. The MHG model forces movement to be only along vertical or horizontal directions. Finally, the SQG model applies the RWG approach to the groups in sequence, i.e., groups are ordered and group i has to move toward the current position of group $i-1$.

We consider a classical reactive routing protocol, the *Dynamic Source Routing* (DSR) protocol, and we perform a thorough evaluation of its behavior under the four proposed group mobility models using as a reference the behavior obtained with the random waypoint model. We observe the high variability of the results and the need to know exactly the behavior of the system and the impossibility to define a unique proposal which is general to whatever environment. We make evident that group mobility pattern highly affects the performance of a routing protocol but also that the mix of inter- and intra-group communication has a strong impact on the routing protocol performance and should therefore be taken into consideration when tuning or designing a routing protocol. Finally, we demonstrate that the presence of groups obviously forces the network topology to be more sparse and therefore the probability of network partitions grows. This phenomenon is especially evident with the SQG mobility model.

The rest of this paper is organized as follows: Section 2 describes the related work dedicated to the analysis of the impact of group mobility over MANETs. Section 3 describes the mobility models we propose, the software tool we designed and outlines the problems with group mobility. Section 4 presents the sensitivity analysis over the performance of DSR with our four mobility models and finally, Section 5 presents the conclusions of this work resuming a few considerations over the approach to be followed to optimize routing protocols.

2 Related work

The most widely used individual-based mobility model is the *random waypoint* model where motion is characterized by two factors: the maximum speed and the pause time. Each node starts moving from its initial position to a random target position selected inside the simulation area. The node speed is uniformly distributed between 0 and the maximum speed. When a node reaches the target position, it waits for the pause time, then selects another random target location and moves again. Many other variations of this model exist which increase the randomness of the mobility process. For example the Random Direction model [9], the Smooth Random Mobility Model [10], or the Random Gauss-Markov Mobility [11].

In a previous work [12] we intuitively described several group-based models like the column model, the pursue model, and the nomadic models. In the first model the nodes form around a reference grid (in this case, a 1-d line), and roam within a constant distance of their point on the grid. When the grid moves, the nodes follow. In the pursue model, a particular node is moving according to one of the independent mobility models, and all other nodes are following this node. Their movement is described in terms of the vector of their current velocity, and the addition of an acceleration and random vector. In the nomadic model, which (along with the others listed above) is a less general form of the Reference Point Group Mobility Model [13], each node is associated with a logical base position. Each base position may have more than one node associated with it. The base positions themselves move according to some mobility model, and nodes associated with each base position stay within some predetermined distance of the base position, moving along with it.

Most of the research in ad-hoc networks is done by using individual mobility models because the simulation code is readily available and because group mobility adds even more parameters to take care of. To the best of our knowledge only two group mobility models have been described in the literature.

The first one, by M. Bergamo et al. [14], is called the *Exponential Correlated Random* (ECR) model and simulates the movement of nodes in a multihop packet radio network in a tactical setting. The model can have several groups of nodes. Each group as a whole moves according to the model, and each node within a group also moves according to the model, but following the trajectory of the group. Given the current position of a node, the next one is calculated as:

$$b(t+1) = b(t) \cdot e^{-\frac{1}{\tau}} + (\sigma\sqrt{1-e^{-\frac{2}{\tau}}}) \cdot r$$

where: b defines the position, τ the location-change rate, and r is a Gaussian distribution with variance σ. A pair (τ , σ) must be defined per each group. The main drawback of this model stands in the complexity to impose a given motion pattern by setting up the proper values for the model parameters.

The second group mobility model presented by X. Hong et al. [13], is denominated *Reference Point Group Mobility* (RPGM). This model presents a general framework for group mobility and can be used to simulated a wide range of mobility models. It defines the concept of group center (*reference point*), as a virtual point that moves following a set of *waypoints* (group motion). Group member experience random deviations from group motion. This model can be used in a variety of ways, as different scenarios can be represented (i.e., meeting room, exposition visit, isolated static groups, etc). The RPGM main drawback is that node motion within a group is restricted to relative low speed motion. Besides, this model leaves too many open parameters, so a lot of choices have to be done to completely specify a simulation setup. The RPGM model can generate topologies of ad-hoc networks with group-based node mobility for simulation purposes, it is not easy to use for partition prediction purposes [15]. This model supposes the presence of an omniscient observer, a so called *God*, which maintains the complete information about the mobility groups including their member nodes and their movements. Due to the distributed nature of these types of mobile networks, such high-level information is not easy to be made available to any mobile nodes at run-time. Moreover, the RPGM model represents the mobile nodes by their physical coordinates. Given only the instantaneous physical locations of the nodes, it is difficult to derive the characteristics the movement of the nodes group movement.

3 The group mobility models

In this work we present 4 different group mobility models which combine the random waypoint model with the concept of group. The models are:

1. The *Random Waypoint Group Mobility Model* (RWG): this model extends the classic random waypoint model applying mobility to a subset of close-by nodes at a time. This is the most straightforward extension which allows to make evident the characteristic of intra- and inter-group data-traffic.
2. The *Random Direction Group Mobility Model* (RDG): while with the RWG model a group destination is normally inside the movement area, with the RDG we stretch the final destination to a border of the movement area. This modification allows to stress routes extensions while reducing the “density waves” [16] effect.
3. The *Manhattan Group Mobility Model* (MHG): the MHG model forces movements to be only along vertical or horizontal directions. We are modelling a

constrained environment where paths can follow only predetermined directions, like in downtown areas.

4. The *Sequential Group Mobility Model* (SQG): finally, the SQG model apply the RWG approach to all the groups in sequence, i.e., groups are ordered and group i has to move toward the current position of group $i-1$. Figure 1 shows a sequence of three *nam* screen-shots which represent the evolution of the network topology when using the SQG model.

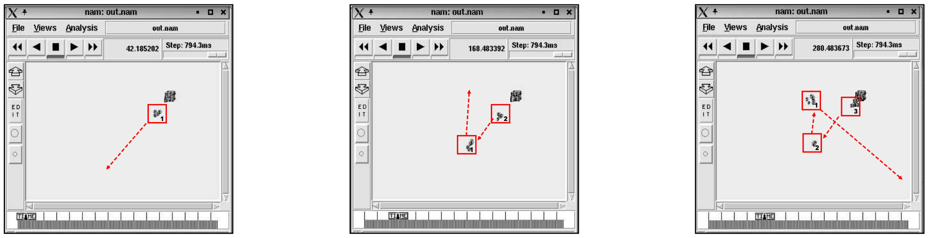

Fig. 1. Sequence of three *nam* screen-shots which represent the evolution of the network topology when using the SQG model.

We designed a mobility pattern generator, called `grcmob`[1], to be used with the ns-2 simulator whose approach is similar to that of the `setdest` module defined by CMU Monarch projects. The user has to define the number of groups, the total number of nodes, the simulation time, the area size, the max speed value and an initial position flag. We assume each group to have a fixed size, i.e., a fixed number of members; nodes are assigned evenly to each group. The initial position flag refers to whether we want to chose a random initial position for groups or we want the same initial position for every group. The concept of group, which can be informally described as a set of *close-by* nodes, is represented in `grcmob` using the notion of *sensitivity*. We introduce three parameters to characterize sensitivity: the *distance_group_sensitivity*, the *group_speed_sensitivity*, and the *group_init_motion_sensitivity*. First of all a single node is used as a reference for the other members of the group. The criteria to chose the reference node is irrelevant; in our case was the node with the lowest id. The *distance_group_sensitivity* indicates the maximum distance between the reference node and any other node in the group. The *group_speed_sensitivity* and the *group_init_motion_sensitivity* parameters are used to give flexibility to the relative movement of each of the member of the group. The first one expresses the range of values for each node speed with respect to the reference node, while the second one expresses when a node starts moving with respect to the reference node.

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[1] The `grcmob` source code is available at http://www.grc.upv.es/.

The presence of groups raises an important issue related to the percentage of data traffic that is sent and received inside the same group, which we will call, *intra-group* data traffic, and the percentage of data traffic that is sent from one group and received inside a different group, which we will call, *inter-group* data traffic. The combination of these two types of traffic strongly impact on the routing protocol. The basic idea is that with intra-group data traffic no actual routing is required because the sender and the receiver are 1 hop away, while if we have a high percentage of inter-group data traffic, the number of hops will increase thus requiring more complex routing protocol. For this reason in the simulations we emphasized the evaluation of the average hops count.

4 Simulations

This Section reports the results of the sensitivity analysis we performed adopting the four mobility models described in Section 3 and using the DSR [6] routing protocol. We fixed to 100 the overall nodes number and employed 20 sources which generated 50% of intra-group data traffic and 50% of inter-group data traffic. We used 4 packets/seconds *Constant Bit Rate* (CBR) data flows with a packet size of 512 bytes. The source data traffic generating pattern was kept unchanged across all simulations.

The group sensitivity parameters were set to describe dense and stable groups. The *distance_group_sensitivity* was set to 50 meters, the *group_speed_sensitivity* was ± 0.15 meters/seconds and the *group_init_motion_sensitivity* was ± 0.15 seconds.

The overall mobility process, as for the random waypoint model, is based on alternating mobility periods and pause periods. The maximum duration for the pause periods, defined by parameter *pause_time*, was set to 20 seconds. This value was obtained by the work described in [16] to improve stability of the results. As a general rule we waited for each node of the group to have completed is movement phase before establishing the next movement for the whole group.

We defined a basic scenario (see Section 4.1), and modified one at a time the following parameters: the node speed, the number of groups, and the simulation area size. The objective was to determine how a specific single parameter affects the results. Regarding the performance metrics we concentrated on: the delivery rate, the route hops count and the end-to-end delay. The delivery rate is obtained by the ratio of the number of data packets delivered to the destination nodes divided by the number of data packets transmitted by the source nodes.

The simulation duration was set to 2000 seconds. During the first 1000 seconds the nodes only moved around and no data traffic was generated. According to [16] this would allow for the system to get to a stable state before data traffic is generated.

4.1 The basic scenario

In this section we describe the basic scenario which is used as a reference for the sensitivity analysis process. We supposed to have 20 groups over an area of

1000 meters×1000 meters and that nodes speed was equal to 3 meters/seconds. Figure 2 shows the results for each mobility model in terms of the data packet delivery ratio, the average hops count, and the average end-to-end delay.

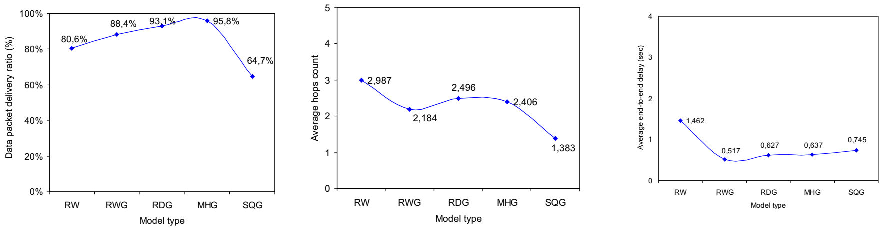

Fig. 2. Performance results for the 100 node MANET basic scenario using the different mobility models.

The random waypoint model shows the highest hops count. This is because all the data packets can potentially need several forwarding nodes. On the other hand, those scenarios using any of the group mobility model have a mixture of intra-group data packets (where no forwarding nodes are required) and inter-group data packets, thus the average hops count decreases with respect to the random waypoint case.

We can also observe that in general the end-to-end delay increases as the hops count increases. With the random waypoint model the delay can be almost three times higher with respect to group mobility models. This is mainly due to the fact that this mobility model suffers the effect of the "density waves" [16]. This phenomenon makes nodes to group around the center of the simulation area thus increasing the level of network congestion multiplying access interference.

In general we cannot observe any significant difference between the RWG, RDG and MHG models. This could be due to the relatively low number of groups that tend to make these scenarios similar. As we will select more dense scenarios we expect some differences to appear especially between the RWG model, where nodes tend to move toward the center of the area, and the RDG model, where nodes travels up to the border of the simulation area.

Finally, the SQG model presents the lowest delivery ratio and hops count. The end-to-end delay of the SQG comes from the high variability that exhibit intra- and inter-group data traffic. Most of the successfully delivered data packets are those from the intra-group connection. On the other hand, the low node speed of the basic scenario makes the SQG model quite sensitive to network partition, so a high percentage of the inter-group traffic do not succeed. Moreover, those inter-group packets that finally succeed have been waiting in intermediate queues for a longer period of time, increasing thus the average end-to-end delay. It is expected that as node's speed increase network partition of this scenario decrease.

The above results must be analyzed taking into consideration the following points:

- with any of the four group mobility models, the 100 mobile nodes are distributed over 20 groups, thus making the resulting network topology much more sparse with respect to the network topology where the 100 mobile are not grouped.
- most importantly, the communication pattern has been selected randomly, with the only requirement of equally balance the inter- and intra-group communication. As stated before, we have 20 sources which generate half of the traffic inside the group and half of the traffic toward external nodes, thus 50% of the data packets do not need any forwarding node to be successfully delivered.

Varying the traffic distribution the performance results vary accordingly. Figure 3 shows the obtained results when varying the percentage of the inter- and the intra-group traffic among values 0%, 25%, 50%, 75%, and 100%.

The traffic delivery rate drops below that of the random waypoint when the percentage on inter-groups traffic exceeds 60%. The presence of groups obviously forces the network topology to be more sparse and therefore the probability of network partitions grows. If we consider the average hops count, increasing the percentage on inter-groups traffic can lead the routing protocol, like in the case of the RWG, RDG, and MHG models, to perform worse than in the random waypoint case. A consequence of the increased value for the average hops count is the increment of the end-to-end delay.

4.2 Impact of nodes speed

In this section, we explore the effect of varying nodes speed over the basic scenario. Figure 4 shows the obtained results when varying the maximum node speed among 3 (basic scenario), 6, 9 and 12 meters/seconds.

Except for the SQG model, all the scenarios present a descendent trend for the delivery rate and the average hops count when node speed increases. This happens because as node speed increases, packets with longer routes could suffer from broken links with the possibility for packets to be dropped.

The four group mobility models behave better than the scenario where no group is selected. The reason mainly stands in the traffic distribution. The traffic model distributes the total traffic to be 50% intra-group and 50% inter-group. Thus, 50% of the packets do not need any forwarding node. It is also important to note that for those scenarios based on groups the data packet delivery ratio is not as high as one would expect because the 50% of the packets (inter-group data packets) could suffer from transient partition that exist in sparse networks.

As node speed increases, the RDG model increases the average hops count with respect to the RWG and the MHG. Nodes that follow the RDG model will

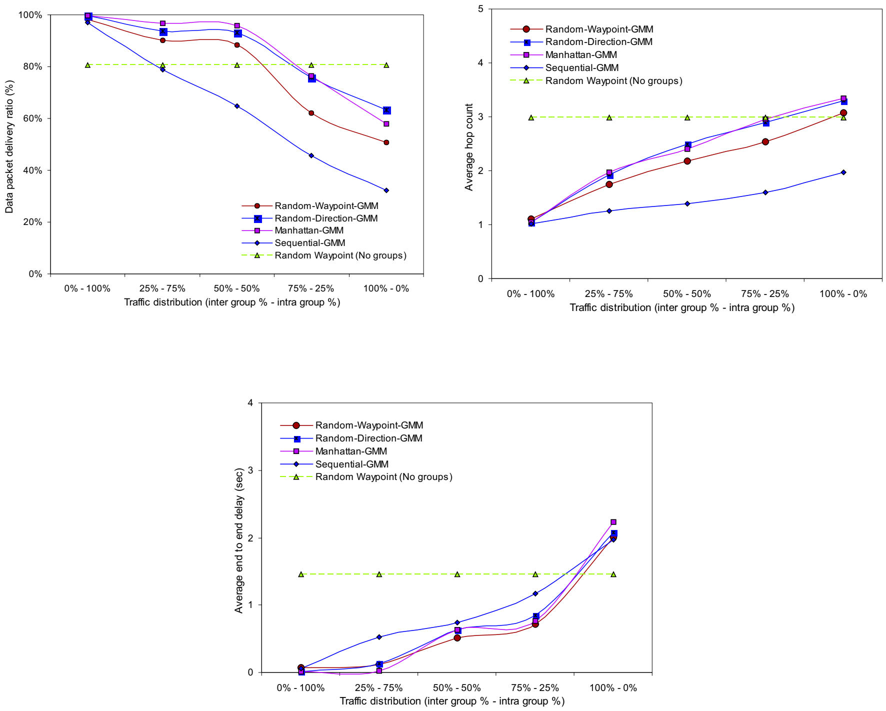

Fig. 3. Performance results for the 100 nodes MANET with five different mobility models as a function of traffic distribution

move up to the simulation area border thus increasing the average number of hops and so the end-to-end latency.

The SQG model behaves better as node speed increases in terms of delivery ratio and end-to-end delay. In this mobility model all the groups follow similar paths, thus as node speed increases, the distance among groups decreases, and the model tends to eliminate the partition that appear when the speed of nodes is low.

Finally, when looking at the details of the average end-to-end delay we can observe that all the models except the SQG increase the latency as node speed increases. As node speed increases, more packets have to wait in intermediate queues for the availability of new paths after a route breakage. However, the effect of congestions observed in the basic scenario using the random waypoint model tend to disappear at high speed because traffic tends to be more evenly distributed due to node's movement.

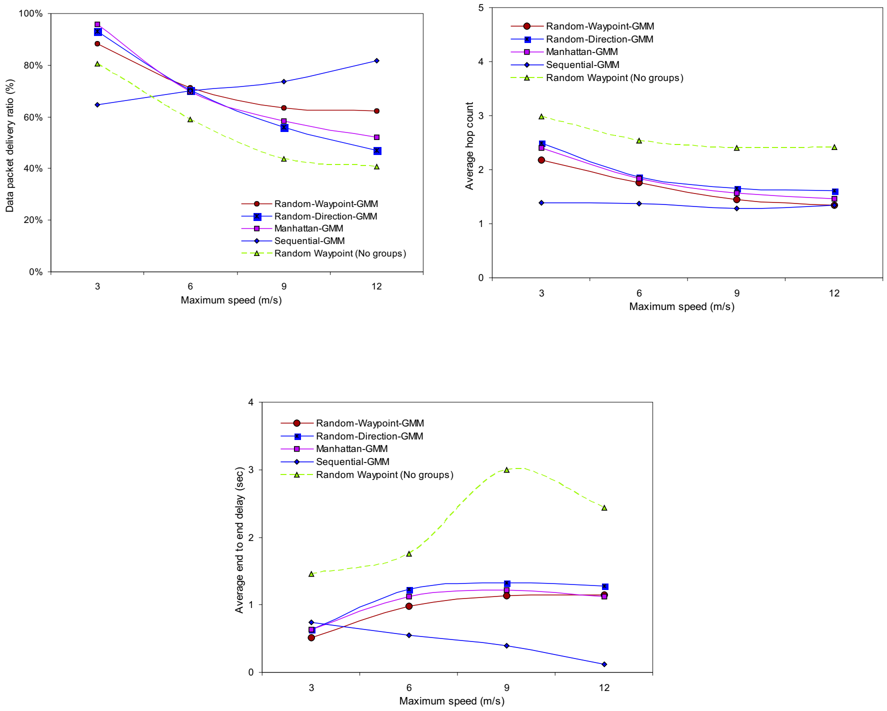

Fig. 4. Performance results for the 100 nodes MANET with five different mobility models as a function of the maximum node speed

4.3 Impact of groups number

We now evaluate how the number of groups can affect performance. Figure 5 shows the obtained results when varying the total number of groups among 1, 10, 20 (basic scenario), and 50. The performance results obtained with the random waypoint model will obviously not be affected. Similarly, when we select just 1 group, all the traffic become intra-group, independently of the mobility model. In that case, the average hop count is 1 hop and nearly 100% of the total packets can be successfully delivered.

As we increase the number of groups, the effect of transient partitions will decrease. As an example, the scenario where we select 50 groups the performance for the four group mobility models approach the random waypoint scenario. However Figure 5 shows that there are still differences. These differences are mainly due to the fact that still 50% of the total traffic do not need any forwarding node. So all the approaches based on groups get better performance in terms of delivery ratio, average hops count and average end-to-end delay.

We can also observe that in the 50 groups scenario, the RDG model gets worst performances in terms of hops count than all the other approaches. This is due to the fact that all nodes in this dense scenario move until they reach the border of the simulation area, thus increasing the average hops count and the end-to-end delay.

The scenarios where only 10 or 20 groups are selected, the RWG, RDG, MHG, and especially the SQG suffer from transient network partitions. This effect is even more visible at low speeds and will provoke packets to be periodically dropped.

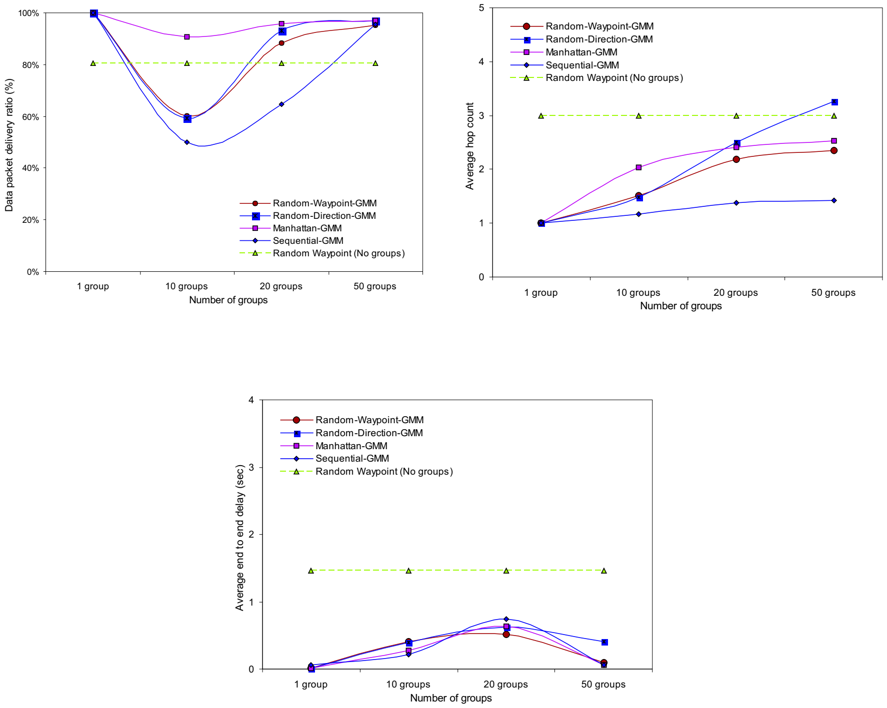

Fig. 5. Performance results for the 100 nodes MANET with five different mobility models as a function of the number of groups

4.4 Impact of the area size

Finally, we evaluate the impact of the simulation area size. Figure 6 shows the obtained results when varying the size of the simulation area from 500 meters×500 meters, 1000 meters×1000 meters and 2000 meters×1000 meters.

In general, as we increase the size of the simulation area all the scenarios need longer routes for routing. Longer routes also affects data packet delivery ratio and average end-to-end delay. The 500 meters×500 meters scenario is dense enough to make all the approaches successfully deliver around 99% of the total data packets.

As we increase the size of the simulation area, we get a quite sparse scenario specially for those scenarios using any of the group mobility models. The performance results obtained for RWG, RDG and MHG in the scenario of 2000 meters×1000 meters are mainly due to the effect of transient partition.

Finally, when we increase the simulation area, the SQG obtain similar performance with respect to the basic scenario. As we previously commented (see Section 4.1) the SQG suffer transient partition even when the simulation area is 1000 meters×1000 meters and when we increase the area its behavior remains just like in the basic scenario.

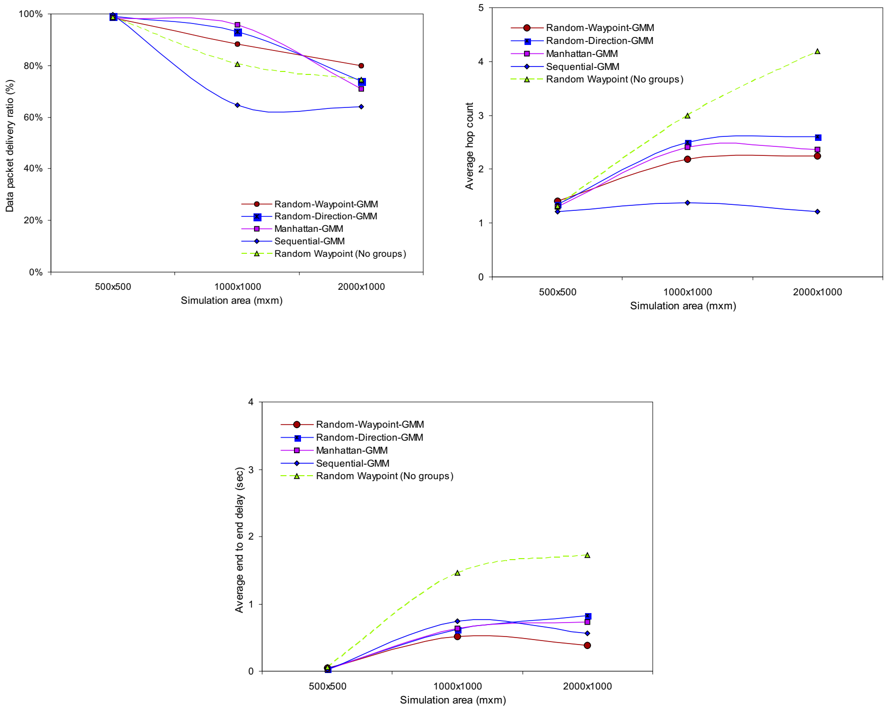

Fig. 6. Performance results for the 100 nodes MANET with five different mobility models as a function of the simulation area size

5 Conclusions

This paper presented an analysis of the behavior of a routing protocol when group mobility is involved. The objective was to prove that the chosen mobility model can deeply affect the performance results of a routing protocol. We concentrate on group mobility because there is a growing attention on the development and evaluation of MANET's approach applied to *personal area networks* (PANs), especially based on Bluetooth technology.

We proposed four different group mobility models: the *Random Waypoint Group Mobility Model* (RWG), the *Random Direction Group Mobility Model* (RDG), the *Manhattan Group Mobility Model* (MHG) and the *Sequential Group Mobility Model* (SQG). We described a group mobility patterns generator called `grcmob` whose approach is similar to that of the `setdest` module defined by CMU Monarch projects to be used with the ns-2 simulator. We compared the behavior of a classical reactive routing protocol, the *Dynamic Source Routing* (DSR) protocol and we perform a thorough evaluation of its behavior using as a reference the behavior obtained with the random waypoint model.

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As a general rule, when intra-group data traffic ratio exceeds the inter-group data traffic the routing protocol can take advantage of group-awareness and optimize table management due to the reduced average hops count. In this context application with a lot of dependence on end-to-end delay can improve their performance due also to the high delivery ratio.

When inter-group data traffic exceeds the intra-group data traffic in general performances get worse due basically to the high sparseness of the network. Finally, the SQG is the mobility model that generally produces the worst result, especially at low speeds. In this case long duration disconnections should probably be handled at the application layer with some form of caching.

Acknowledgments

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