Evaluating the Performance Impact of Group Mobility in MANETs

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Resumen— **We present an analysis of the effect that mobility models have over the performance of a mobile ad hoc network. 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 investigate the effect that the mobility model has on the performance of CBR traffic and TCP traffic. We propose four different group mobility models and describe a mobility pattern generator called `grcmob` to be used with the ns-2 simulator. We perform a thorough evaluation of MANET behavior using as 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 group mobility pattern highly affects the performance of both CBR traffic and TCP traffic. Also, the mix of inter- and intra-group communication has a strong impact on the MANET performance and should therefore be taken into consideration when tuning or designing MANETs protocols.**

I. 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. Developing core protocols (at different layers, e.g., MAC and network layers) for MANETs has been an area of extensive research in the past few years where the *Internet Engineering Task Force* (IETF) MANET working group [2] has contributed with various protocols for *ad hoc* networks. 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 [6] or the GloMoSim [9], 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., [10] showed that these models can have a great effect upon the results of the simulation, and thus, on the evaluation of these protocols.

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 most widely used individual-based mobility model is the *Random Waypoint* [1] model where motion is characterized by two factors: speed and 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.

One of the most cited group-based mobility models is the *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.

The objective of this work is to show the impact that group mobility has over the transmission of TCP and CBR traffic in a MANET. We compare the results with the classic *random waypoint* 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 [8].

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 perform a thorough evaluation of MANET behavior under the four proposed group mobility models using as 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 as well as the impossibil-

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This work was partially supported by the Spanish CICYT under Grant TIC2003-00339 and by the *Junta de Comunidades de Castilla la Mancha*, Spain, under Grant PBC-03-001.

ity to define a unique proposal which is general to whatever environment. We make evident that group mobility pattern highly affects the performance of a MANET but also that the mix of inter- and intra-group communication has a strong impact over performance and should therefore be taken into consideration. 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 II describes the mobility models and the software tool we designed and outlines the problems with group mobility. Section III presents the sensitivity analysis over the performance of a MANET using both CBR and TCP traffic with our four mobility models. Section IV concludes the paper.

II. 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" [5] 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 $i-1$.

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 members 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.

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. Intuition suggest that the combination of these two types of traffic will strongly impact performance. 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.

III. Simulations

This Section reports the results of the sensitivity analysis we performed adopting the four mobility models described in Section II. All results are based on a network configuration consisting of TCP-Reno and CBR traffic communicating over an 802.11 wireless network with routing provided by the *Dynamic Source Routing* (DSR) protocol.

The choice of the DSR as the routing protocol was primarily based because while being simple it was shown to be one of the most efficient routing protocols, especially in bounded regions [4]. However since our goal was to observe the impact that the mobility model has over the performance of CBR traffic and TCP traffic, any of the routing protocols proposed for mobile ad hoc networks would have sufficed.

We fixed at 100 the overall number of nodes and employed 20 sources which generated 50% of intra-group data traffic and 50% of inter-group data traffic. We consider two different data traffic patterns: 20 *Constant Bit Rate* (CBR) data flows, each one generating 4 packets/seconds with a packet size of

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

512 bytes and 20 TCP-Reno connections between the same pairs of senders and receivers that in the previous case. We configured each TCP connection to generate data packets of 512 bytes using a maximum window size of 32 packets. 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 [5] to improve the stability of the results. As a general rule we waited for each node of the group to have completed its movement phase before establishing the next movement for the whole group.

We defined a basic scenario (see Section III-A), and modified one at a time the following parameters: node speed and number of groups. The objective was to determine how a specific single parameter affects the performance results. Regarding the performance metrics we study the delivery rate, the route hops count and the end-to-end delay when the traffic consists of CBR flows and the average goodput when selecting TCP connections. 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 one. As far as the average goodput, it measures the total number of bits received at the destination divided by the simulation time. This measure does not include neither packet headers nor overhead.

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 [5] this would allow for the system to get to a stable state before data traffic is generated.

A. The basic scenario

In this section we select the basic scenario which is used as a reference for the sensitivity analysis process. We have 20 groups over an area of 1000 meters×1000 meters and node speed is equal to 3 meters/second. Table I shows the characteristics of the basic scenario according to the different mobility models in term of number of link changes and the theoretical number for the of destination unreachable counts.

The destination unreachable counts measures how many source-destination pairs can not communicate at some time along the total simulation time. It gives an idea of how partitioned the network is. On the other hand the number of link changes represents how many links break due to mobility. Both indexes could affect performance. For instance, as link changes increase, the number of route changes also increase with a negative effect on CBR and specially on TCP Performance [7]. On the other hand as the number of destination unreachable increase, the probability that some of the selected data flows could not succeed due to network partition also increase, thus affecting TCP goodput and also CBR delivery ratio.

TABLA I
CHARACTERISTICS OF THE BASIC SCENARIO.

	Destination Unreachable	Link Changes
RW	0	14051
RWG	4930	15503
RDG	10020	10441
MHG	5720	10314
SQG	3490	4888

We can observe that the scenario using the random waypoint model represents a totally connected network. On the other hand, those scenarios using any of the models based on groups suffers from some network partition that could adversely affect performance. The SQG model has the lowest number of destination unreachable and link changes. Finally the RDG has the highest number of destination unreachable, because this mobility model tends to make the network more sparse.

A.1 Results for CBR data traffic

We first evaluate the effect over the basic scenario when the data traffic consists of CBR flows. Table II 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.

TABLA II
PERFORMANCE RESULTS FOR THE BASIC SCENARIO.

	Delivery ratio	Hop Count	Delay (s)
RW	0.806 (%)	2.987	1.462
RWG	0.884 (%)	2.184	0.517
RDG	0.931 (%)	2.496	0.627
MHG	0.958 (%)	2.406	0.637
SQG	0.647 (%)	1.383	0.745

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 models have a mixture of intra-group data packets (where no forwarding nodes are required) and inter-group data packets. So 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" [5]. 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 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 travel 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 does 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 increases network partition in this scenario will 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 nodes are not grouped.
- most importantly, the communication pattern has been selected randomly, with the only requirement of equal balance between 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 towards external nodes. Thus, 50% of the data packets do not require any forwarding to be successfully delivered.

It is expected that by varying the traffic distribution the performance results vary accordingly. Figure 1 shows the obtained results when varying the percentage of the inter and the intra-group traffic among values 0%, 25%, 50% (basic scenario), 75%, and 100%.

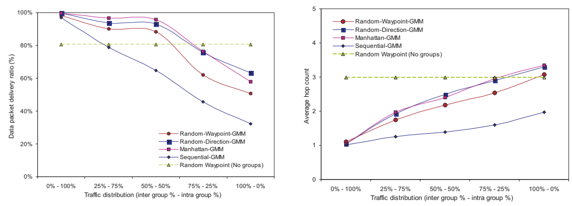

Fig. 1. Performance results as a function of traffic distribution, (CBR traffic).

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-group 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.

A.2 Results for TCP data traffic

We now evaluate the impact that mobility has over the performance of the basic scenario when the data traffic consists on TCP connections. Table III-A.2 reports the total aggregated goodput for each mobility model.

	Goodput (Kbps)
Random-Waypoint-GMM	772,93
Random-Direction-GMM	710,28
Manhattan-GMM	800,99
Sequential-GMM	477,72
Random Waypoint	446,59

TABLA III

Goodput for the basic scenario.

We observe a similar behavior between the RWG, RDG and MHG models, were the aggregated goodput for the 20 TCP connections rounds 800 Kbps. The RWG, RDG and MHG models could benefit from the traffic distribution where 50% of the traffic does not need any intermediate forwarding node. Moreover, since we distribute all the nodes in an area of 1000 meters×1000 meters by using a transmission range of 250 meters some of the 20 TCP connections could go ahead in parallel without any interference.

On the other hand, the SQG and the random waypoint achieve a worse performance where the aggregated goodput rounds 500 Kbps. The variation in goodput for this two models are due to different reasons. The SQG model uses the same initial position for all the groups. Moreover, the different groups follow similar trajectories and traffic is concentrated in nearby areas since TCP connections transmit in a congested network environments, TCP performance is degraded. As far as the random waypoint model, we have a quite more dense network where the traffic uses longer routes (on average 1.8 hops). As shown in [3] the TCP performance decreases rapidly when the number of hops is increased from 1 hop.

As in the previous case, by varying the traffic distribution the performance results vary accordingly. Figure 2 shows the obtained results when varying the percentage of the inter and intra-group traffic among values 0%, 25%, 50% (basic scenario), 75%, and 100%.

The total aggregated goodput drops sharply as the

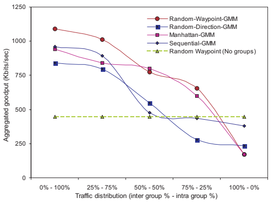

Fig. 2. Aggregated goodput as a function of traffic distribution, (TCP traffic).

percentage of inter-group traffic increases. This effect is due to two main reasons. First of all, as the inter-group traffic increases the number of TCP connections that require intermediate nodes increases, and so the average number of hops also increases with a gradual degradation of the TCP performance. On the other hand, all of the models based on groups have potential problems with network partitions (see Table I). Moreover, the probability that the 20 TCP connections, have problems with network partition increases as the inter-group traffic increases.

B. Impact of nodes' speed

In this section, we explore the effect of varying nodes speed over the basic scenario. While the SQG and the random waypoint models maintain a quite steady behavior in term of unreachable nodes, the other three mobility model increase the number of unreachable nodes as node speed increases. As far as route stability, we can observe that, except for the SQG model, the other models increase the number of broken links as node speed increases.

B.1 Results for CBR data traffic

Figure 3 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 groups are formed. 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 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 effects that appears when the speed of nodes is low.

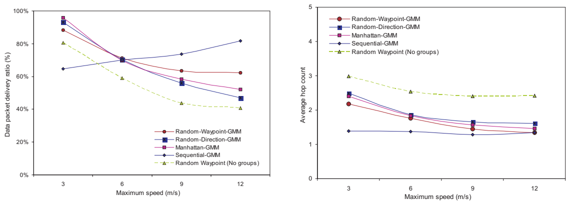

Fig. 3. Performance results as a function of the maximum node speed, (CBR traffic).

B.2 Results for TCP data traffic

When we take TCP connection as data traffic, goodput drops as node speed increase independently of the mobility model. We suspect that this behaviour has to do with the TCP's inability to recognize the difference between link failure and congestion. As node speed increases, link failure happens more frequently resulting in a degradation of TCP goodput.

C. Impact of the number of groups

We now evaluate how the number of groups can affect performance. Those scenarios using 1 or 50 groups result in a completely connected MANET, where the number of unreachable nodes and link changes tend to 0. As we increase the number of groups to 10, we have a quite sparse network where the potential number of network partitions and link changes sharply rises for those models based on groups. Finally, as we move from 10 to 20 groups the potential problems with network partition drops and the number of link changes become stable.

C.1 Results for CBR data traffic

Figure 4 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 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 approaches the random waypoint scenario. However Figure 4 shows that there are still differences. These differences are mainly due to the fact that still 50% of the total traffic does not need any forwarding nodes. So, all the approaches based on groups get better performance in terms of delivery ratio, average hops count and average 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.

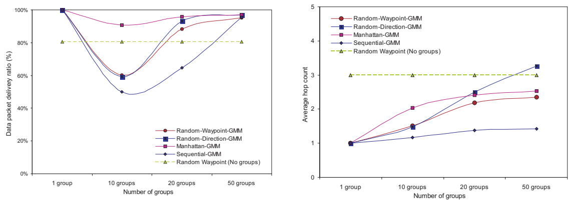

Fig. 4. Performance results as a function of the number of groups, (CBR traffic).

C.2 Results for TCP data traffic

Figure 5 shows the obtained results when varying the total number of groups among 1, 10, 20 (basic scenario), and 50. The scenario where only 1 group is selected, represents the reference case. In this scenario all the TCP sources are trying to send data packets in the same area, thus competing for the channel. The total channel capacity must be shared among the 20 TCP connections and so the aggregated goodput is the minimum. As we increase the number of groups to 10 and 20 groups the number of potential TCP connections that can transmit in parallel increases, thus increasing the total aggregated goodput. Finally, as we rise the number of groups to 50, the scenarios no longer suffer from network partitions but the selected routes become longer. As commented in Section III-A.2 TCP performance drastically drops as routes become longer.

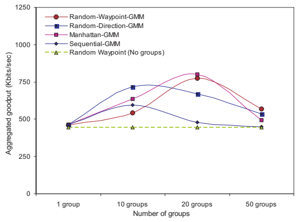

Fig. 5. Aggregated goodput as a function of the number of groups, (TCP traffic).

IV. CONCLUSIONS

This paper presented an analysis of the effect that the mobility models have in the performance of a mobile ad hoc network. The objective was to prove that the chosen mobility model can deeply affect the performance results. We concentrate on group mobility because there is a growing attention on the development and evaluation of a MANET's approach applied to *personal area networks* (PANs), especially those based on Bluetooth technology. We investigate the effect that the mobility model has on the performance of CBR traffic and TCP traffic.

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 pattern 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 perform a thorough evaluation of MANET behavior using as reference the behavior obtained with the random waypoint model.

We observe the high variability of the results, 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 patterns highly affect the performance of both CBR traffic and TCP traffic, but also that the mix of inter- and intra-group communication has a strong impact on the performance and should therefore be taken into consideration when tuning or designing protocols for MANETs. Finally, the presence of groups obviously forces the network topology to be more sparse and therefore the probability of network partitions grows.

REFERENCIAS

[1] David B. Johnson and David A. Maltz. *Dynamic Source Routing Protocol in Ad hoc wireless Networks*, chapter 5, pages 153–181. Kluwer Academic Publishers, 1996.

[2] I. E. T. Force. Manet working group charter. http://www.ietf.org/html.charters/manet-charter.html.

[3] G. Holland and N. H. Vaidya. Analysis of TCP performance over mobile ad hoc networks. In *Proceedings of IEEE/ACM MOBICOM '99*, 1999.

[4] Juan Carlos Cano and Pietro Manzoni. A performance comparison of energy consumption for mobile ad hoc networks routing protocols. *IEEE/ACM MASCOTS 2000: Eighth International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems*, August 2000.

[5] Jungkeun Yoon, Mingyan Liu, and Brian Noble. Random waypoint considered harmful. *Proceedings of IEEE INFOCOMM 2003, San Francisco, California, USA*, March 30-April 3 2003.

[6] K. Fall and K. Varadhan. ns notes and documents. The VINT Project. UC Berkeley, LBL, USC/ISI, and Xerox PARC, February 2000. Available at http://www.isi.edu/nsnam/ns/ns-documentation.html.

[7] K. T. M. Gerla and R. Bagrodia. Tcp performance in wireless multi-hop networks. In *Proceedings of IEEE WMCSA'99, New Orleans, LA, USA*, 1999.

[8] P. M. of Bluetooth SIG. *Specification of the Bluetooth System - Core. Version 1.1.* Bluetooth SIG, Inc., February 2001.

[9] Xiang Zeng, Rajive Bagrodia, and Mario Gerla. Glomosim: a library for parallel simulation of large-scale wireless networks. In *Proceedings of the 12th Workshop on Parallel and Distributed Simulations – PADS '98, Banff, Alberta, Canada*, May 1998.

[10] Xiaoyan Hong, Taek Jin Kwon, Mario Gerla, Daniel Lihui Gu, and Guangyu Pei. A mobility framework for ad hoc wireless networks. *Proceedings of the Second International Conference, MDM 2001 Hong Kong, China, LCNS Vol. 1987*, pages 185–196, January 2001.