GROUP FORCE MOBILITY MODELS AND THEIR OBSTACLE AVOIDANCE CAPABILITY

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***Abstract*—Many mobility models attempt to provide realistic simulation to many real world scenarios. However, existing mobility models, such as RPGM [1] and others, fail to address many aspects. These limitations range from MN collision avoidance, obstacle avoidance, and the interaction of MNs within a group. Our research, the Group Force Mobility Model (GFMM) [2] proposes a novel idea which introduces the concept of attraction and repulsion forces to address many of these limitations. [2] describes some of the limitations and drawbacks that many models neglect. This model effectively simulates the interaction of MNs within a group, the interaction of groups to one another, the coherency of a group, ad the avoidance of collision with groups, nodes, and obstacles. This paper provides a survey analysis of obstacle mobility models which are geometric- and non-geometric based and those which are geographic constrained and non-geographic constrained. In addition, we illustrates the GFMM's ability to avoid collision with obstacles, which is a vital property to posses in order to provide a realistic simulation. We compare our model with the commonly used RPGM model and provide statistical assessments based on connectivity metrics such as link changed, link duration, and relative speed. All will be detailed and explained in the paper**

***Index Terms*— Group Mobility, Force, Collision Avoidance**

I. INTRODUCTION

Mobility models have been created over the years to attempt to accurately simulate movement of mobile users in mobile adhoc networks (MANETS). There have been many models to try to capture as much of an optimal situation as possible. However, because of the infinite number of combinations and unknowns, all have some drawbacks to them. The best approach has been to narrow the motivation of the model and achieve that as best as possible.

Most models are characterized into individual mobility or group mobility. Individual mobility includes the widely popular Random Waypoint Model (RWP) [3]. In this model, each mobile node (MN) is randomly placed in a simulation and a given a random destination. The mobile node navigates to that destination. Once the destination is reached the MN will pause for a set time, determine another destination, and after pause time proceed to that location. This model is frequently used in studies regarding simulation and mobility and many models pattern themselves after RWP. Such mobility models include Random Direction [3] and Random Walk [3]. As noted in [4], there are drawbacks to RWP and similar models derived from it. RWP and its subsidiaries have mobile nodes that move throughout an area without barriers, obstacle, or any restricting elements. Furthermore, they are entity mobility models [3] which focus on the independent movement of mobile nodes. This is a drawback to scenarios such as military/battlefields, school campuses, or any other communications which emphasize on grouping of dependent mobile nodes.

Group mobility models attempt to address the spatial dependency limitations of entity mobility models. These models capture other realistic situations which need simulating (situations such as disaster relief, battlefield communication, and vehicle traffic interaction [3]). The most common of the group mobility models is the Reference Point Group Mobility (RPGM) model.

Essentially, RPGM contains a group leader and group members. The group leader is given a random location, speed, and direction. The group members' information is a varying deviation from the group leaders'. The group members' movement is dependent directly on the movement of the leader. Other group mobility models include the Column Mobility Model [3], Pursue Mobility Model [3], Nomadic Community Model [3], and Structured Group Mobility Model (SGMM) [4]. Again, there are some drawbacks to these group mobility models. For instance, similar to the entity mobility models these models do not consider obstacles, walls, barriers, and other geographically restricted scenarios which would provide a more realistic depiction of mobile user interaction amongst others and the environment.

To address the limitations of entity mobility models and the above mentioned group mobility models, several models have been developed. The Pathway Model [3], Obstacle Mobility Model (OM) [5], Delaunay Model [6], and Obstacle Constrained Group Mobility Model (OGCMM) [7]. Besides OGCMM, all of these models address the scenario of geographic restricted but do not include group movement. The details of these models will be described in a later section of this paper.

The goal of our research is to provide a mobility model which addresses many of the shared limitations describe previously and other limitations that were ignored by some models. Our Group Force Mobility Model (GFMM)[1] attempts to provide a model which can more realistically simulate real world scenarios by tackling many of these limitations and drawbacks.

GFMM not only focuses on group interaction and movement, it provides the capability to incorporate obstacles into a simulation area and give the groups the ability to maneuver around them. Furthermore, it also provides group coherency and prevents mobile nodes for colliding and overlapping with one another which many mobility models failed to incorporate. These capabilities will be detailed in later sections.

The motivation of this paper is to illustrate the benefits of GFMM, how it is used, demonstrate how it can provide the ability for group mobile nodes to avoid obstacles and other geographic constraints, and compare with other obstacle mobility models.

The following sections of this paper are organized as follows: we provide a survey approach which illustrates the various obstacle mobility models in Section II. In Section III, we present the GFMM. Section IV provides a comparative study, and Section V concludes the paper.

II. GEOMETRIC AND NON-GEOMETRIC BASED OBSTACLE MOBILITY MODELS

There are many mobility models which make efforts to provide solutions to either specific real world situations or more general all-encompassing scenarios. The first way is much easy than the latter. Similar to a model that ignores all elements, a mobility model which isolates a specific situation or scenario can be developed much easier than an all-encompassing model because the scope of the work and goal of the model is more specifically defined. However, the problem with this is that it provides many drawbacks and lacks the flexibility to address as many realistic and random situations.

The Freeway, Manhattan and Pathway Models [3] are examples of models which provide geographic constraints, and they are less flexible in application. The movement of the mobile nodes is restricted to a specific path which can be viewed as a street or highway. Similar to the Random Waypoint, a destination is selected the mobile nodes move to that destination, pause, and then choose another destination. The difference is these MNs must follow as specific path.

A. Geometric-based Obstacle Models

The Obstacle Model (OM) includes mobile nodes which must change their movement in order to avoid obstacles and other barriers. However, in OM obstacles affect both the movement of the mobile nodes and the propagation of the radio waves [5]. [5] discusses the three mobile scenarios illustrated Johansson, Larsson, and Hedman et al. in [8] to demonstrate realistic mobile movement.

- Disaster Relief
- Event Coverage
- Conference

However, in these three scenarios each mobile node has an individual and independent motivation that the other nodes in the simulation. No group aspect is represented.

OM determines how mobile nodes avoid these obstacles by constructing Voronoi-diagram pathways [5], and restricting the mobile nodes to move along those paths. The Voronoi graphs are constructed by considering the corners of each obstacle as location points and each corner is a section of the large finite square region. The pathways consist of the vertices of the graphs and intersections between outer boundary of the square region and the graphs. OM also introduces the idea of doorways which implies pathways which extends through the obstacle. Therefore, doorways are defined as the intersections of the graphs and the obstacles. The formulation of these graphs and their use as pathways classifies OM as a geometric-based approach to obstacle avoidance.

Some drawbacks to OM are the paths which restrict the movement of the nodes and prevent them from moving freely. Many scenarios can be at a disadvantage from such restriction. Another drawback to OM is that each obstacle is considered a building or a structure in which a mobile node can pass through therefore, the shortest path to a destination may have gone through an obstacle. In many situations this would not be the most practical or even possible option. As a result, D. Huang introduced the Delaunay Model an obstacle detour mobility model [6].

Again, this method uses a geometric-based approach to avoid obstacles. Instead of Voronoi paths, it uses Delaunay Triangulation to calculate pathways, and these paths are intended to avoid the obstacles and not pass through them. The Delaunay model is described in [6] as an improvement of the Voronoi model in OM based on the comparison of:

- Detour paths on all gaps
- Delaunay model provides shorter paths
- Delaunay model has more paths.

In OM, the construction of the pathways is from identifying the center points as the corners of the obstacles in the simulation area. However, the Delaunay model creates is detour paths by using multiple centerpoints and the midpoint of each Delaunay edge is the endpoint for a detour path. Paths that pass through the obstacle are either deleted or modified based on the intersection points. If a path intersects an obstacle at two parallel sides, then it is deleted. However, paths which intersect the obstacle at sides which are perpendicular or non-parallel are replaced by two line segments that which do not intersect the obstacle completely.

In comparison to Voronoi-graph models, Delaunay also constructs more paths and shorter detour paths. But again, the Delaunay model also does not have any group structure or mobile node collision avoidance capability.

B. Non-Geometric-based Obstacle Models

Finally, the Obstacle Constrained Group Mobility Model is a non-geometric approach which incorporates the movement of nodes in a group formation. Unlike OM, OGCMM does not use pathways to restrict the movement of mobile nodes. The pattern of movement for OGCMM is based on the Reference Point Group Mobility Model [1] unless an obstacle is in the line of sight of the MN’s destination. If an obstacle prevents the mobile node from moving freely and directly to the destination point, the MN randomly chooses a location on the path of the reference point’s pathway until the destination is within the line of sight and not obstructed by and obstacle. The reference point pathway will be a line which passes close to the mobile nodes pathway and possibly through the obstacle. The reference point itself is defined as within the line of sight to the mobile node's destination. Therefore, if no random position along the pathway produces a clear line of sight, then the MN will choose the location of the reference point and move to the destination from that point. Like OM, the OGCMM also allows for mobile nodes to move through an obstacle (assuming that this obstacle is some structure similar to a building). Again, one drawback is that it doesn't consider impenetrable objects such as trees, statues, cars, etc. This can be useful in multiple situations such as disaster relief where people would attempt to avoid collisions with such stationary objects, aerial vehicles avoiding tall trees, mountains, etc.; and even students on campus maneuvering around such objects.

Because of the many constraints and drawbacks in the previous models, in conjunction with other limitation from additional models, our research focuses on addresses those.

Our GFMM [1] is also a non-geometric based obstacle model which utilizes the concept of mobile nodes avoiding collisions with other nodes, other groups, and static obstacles The motivation of the idea comes from the work done by Helbing, et al. [9] and Gloor, et al. [10][11]. Helbing introduces a concept of a social force model which simulates the intent of movement of humans under panic situations. Gloor, et al. continues this idea and applies the social force concept to demonstrate the interaction of humans in harsh mountainous environments.

Our research in developing GFMM employs this force concept to implement the simulation of MN movement. It introduces attraction and repulsion to dictate the change in direction and or speed of mobile nodes. These forces attract MNs to a destination; repel MNs from colliding with each other; and attract MNs to form groups.

C. Discussion

There are various obstacle mobility models which either section a planar area in a geometric approach to construct geographic constrained pathways for MNs to maneuver throughout a simulation area; or models which utilizes a more freely and random movement to destinations. Also, several obstacle models consider MNs and the ability to pass through these obstacles ignoring the idea of obstacles which may be impenetrable. Although such obstacle models such as Delaunay Model creates detours around obstacles, it restricts the mobile nodes along a certain path. The GFMM exploits the limitations which forces these nodes to matriculate along designated paths and passing through obstacles. It is a mobility model which uses force concepts to avoid obstacles and random movement to prevent geographic constraints.

III. GFMM

This section discusses the general concept of the GFMM. It illustrates how the forces are used to attract and repel in order to form groups, avoid mobile node overlap, prevent collisions, and avoid obstacles.

A. Mobile Node Interaction and Group Formation

In GFMM a node will evaluate what necessary action it should take based on the properties of its neighbors. For neighboring nodes which are located within a certain range, the evaluating node will determine if the node belongs to the same group or different group. Based on this information the evaluating node will calculate a repulsion or attraction force between itself and the neighbor node. For all nodes that are not part of the evaluating node's group, Helbing's exponential force decay equation is modeled to repel them and disallow joining the group and avoiding colliding with them. Below is equation 1 which illustrates the equation used to calculate repulsion force of non-group members.

$$\bar{f}_{ij} = A_{ij} \exp\left(\frac{d_{ij}}{B_{ij}}\right)\left(\frac{\bar{r}_i - \bar{r}_j}{d_{ij}}\right) \quad (1)$$

$\bar{f}_{ij}$ is the force exerted on MN i by the neighbor node j; $\bar{r}_i$ and $\bar{r}_j$ are the position vectors of the mobile nodes; d_{ij} is the distance between the two position vectors, $\left|\bar{r}_i - \bar{r}_j\right|$. As the distance between the two nodes increases the strength of the force exponentially decreases. A_{ij} and B_{ij} are simulation chosen constants.

Neighboring nodes which are members of the evaluating node's group experience both repulsion and attraction forces. The attraction force is to maintain the formation of the group. The repulsion force prevents group members from coming too

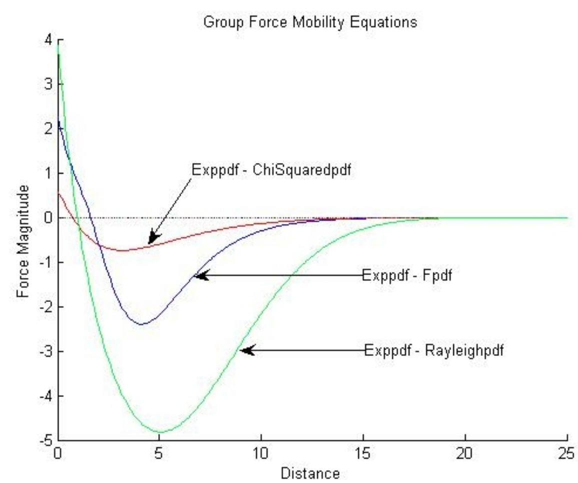

Figure 2. Combined Forces

close to the neighboring, colliding, or overlapping the neighboring node. Essentially, one equation which combined both of these forces is modeled to allow the node to determine what direction to move based on what force. Equation 2 below shows this equation which combines both forces. The repulsion force in equation 2 is the force represented in equation 1. Both α and β are simulation constants which can control the individual magnitudes of the forces, and constant A_{ij} effects the total strength force.

$$\bar{f}_{ij} = A_{ij}\left(\alpha \cdot RepulsionFo\ rce - \beta \cdot Attraction\ Force\right)\bar{r}_{ij}\ , \quad (2)$$

As explained in [] the group formations of the nodes are based on two characteristics: tight and loose. Tight describes the closeness of the nodes in the group and the inability to wander separately from it. The movements are more inter-related to one another as opposed to loose groups which allow the group members to possibly escape from the group and it is less structured.

Our research chose probability distribution functions to model the attraction force which provides these loose and tight group formations. Three pdf's were chosen. Individually these represent the attraction force in equation 2. The first pdf was Chi-Squared pdf (the loosest). The second and moderately loose/tight was Rayleigh pdf. The tightest group forming pdf was the F-Snecedor.

When choosing these pdfs we had to determine what functions when deducted from the exponential function would provide and oscillation of values. The first set of values was particularly high positive values in the y-axis at a very small value of x (representing repulsion). Once x increased the value in the y direction decreased until the y values were negative representing attraction. The x axis represents the distance between the nodes and the y axis is the magnitude of the force (positive: repulsion and negative: attraction). Figures 1 and 2 below illustrate the individual pdf equations and the combined modeled equation respectively.

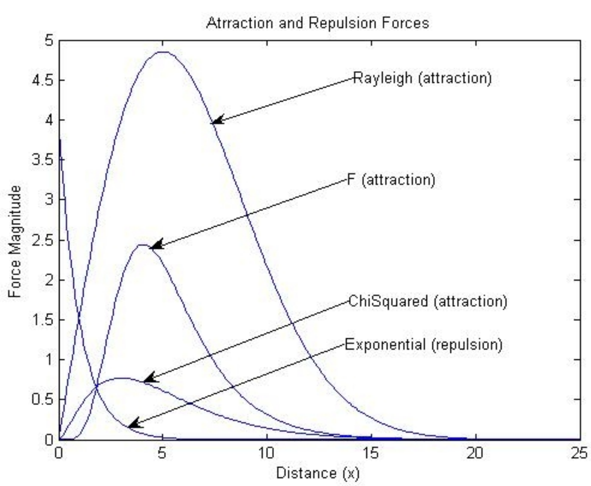

Figure 1. Attraction and Repulsion Forces

B. <u>Node Movement and Collision Avoidance</u>

Generally, the MNs move similar to RWP model but in a group fashion. Each node is randomly given a position and destination. Nodes in the same group are placed within a certain range of one another and their corresponding destinations are similarly close. In addition, the speed of the nodes within a same group deviate slightly from one another. In essence, each group is assigned a central position, group speed, and group destination; and the nodes belonging to that group will have properties (position, destination, speed) relative to the group information.

During the simulation each node evaluates its movement based several factors. These include its current location, the location of the destination, its speed, and the location of neighboring nodes. For every time unit an evaluating node determines if neighboring nodes are within and effecting range. An effecting range means that a node is close enough to have an attractive or repulsive force effect. Essentially, similar to a free-body diagram the evaluating node sums up all the effecting forces in range to calculate on resulting force vector. The direction of this vector is added to the intended direction of the evaluating node towards its destination. The result is the actual direction the node will move. To determine the new direction vector, the current direction vector is multiplied by a weighted variable α, and added to the function Γ which converts the summation of $\bar{f}_{ij}$ for all neighboring nodes to a direction vector. Equation (2) shows this

$$\bar{d}_n = \alpha\ \bar{d}_o + \Gamma\left(\sum_{j \neq i} \bar{f}_{ij}\right), \quad (2)$$

where $\bar{d}_u$ is the new direction vector, and $\bar{d}_o$ is the current direction vector. The gamma function is used to simplify the simulation by converting the force directly into a direction vector. By multiplying the current direction unit vector by a factor of α, this ensures that the MN will continue to move along the path to the intended destination.

This change in direction increases the mobility of the simulation, but more importantly provides the capability to avoid collision with other nodes and obstacles. In GFMM, an evaluating node will have the ability to attract to another node if it is a group member, however the evaluating node will repel all nodes if the distance between the neighboring node and itself is too close. The distance in which the evaluating node begins to repel a node is based on the forces in Figure 2. At the point where the values of x (distance) are positive the node exerts a repulsion force preventing collision and overlap.

C. <u>Obstacle Avoidance</u>

Each obstacle is treated in a similar fashion. There is not any attraction force for a MN to an obstacle. However, as a MN moves throughout the simulation area it evaluates the location of any obstacles within a certain distance of itself. If obstacles reside within this evaluation radius then the exponential force decay equation (1) is applied to calculate the repulsion force between the obstacle and the MN. Again this force is added to the force direction towards the destination. As a result the MN will move around the obstacle in range and continue towards its destination.

Figure 3 illustrates 6 groups of nodes and 6 obstacles in a 600m x400m simulation area. Currently, the obstacles are represented as circles similar to the MNs. The obstacles are displayed larger to differentiate from MNs.

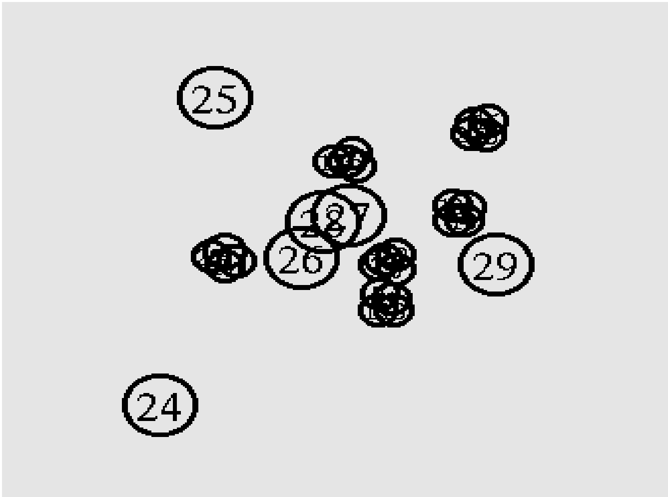

Figure 3. MNs and Obstacles

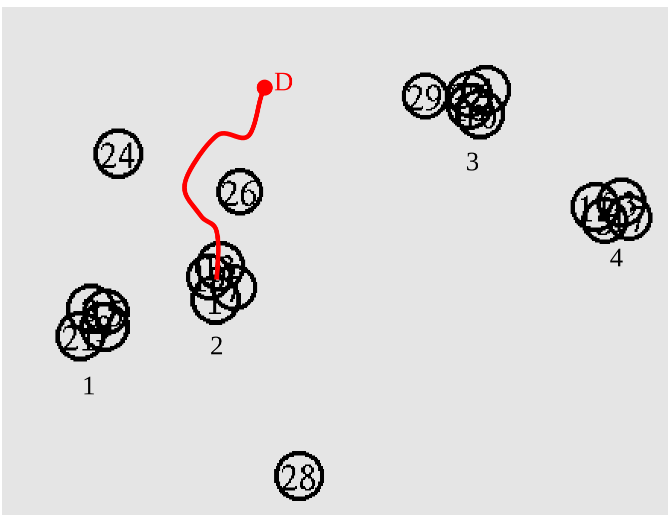

Figure 4. Group Avoiding Obstacle

The above Figure 4 illustrates how a group would perceive to avoid an obstacle in the path of its destination. The red line is an approximation of how group 2 would maneuver around obstacle 26 to reach the destination point D. As the group approaches obstacle 26 the repulsion force from the obstacle causes each group member node to change its direction and migrate around the obstacle. The following figures are snapshots of how this will occur and show group 2 following the path approximation.

D. <u>Reachability</u>

For the purpose of our research and because our simulation tool, *ns2*, is a 2-dimensional program, our obstacles are assumed to extend indefinitely along the z-axis. This concept will interfere with the links between mobile nodes. A line-of-sight approach is taken to determine if a node is reachable to another node. In essence, if an obstacle lies in the path between two nodes, then those nodes are deemed unreachable

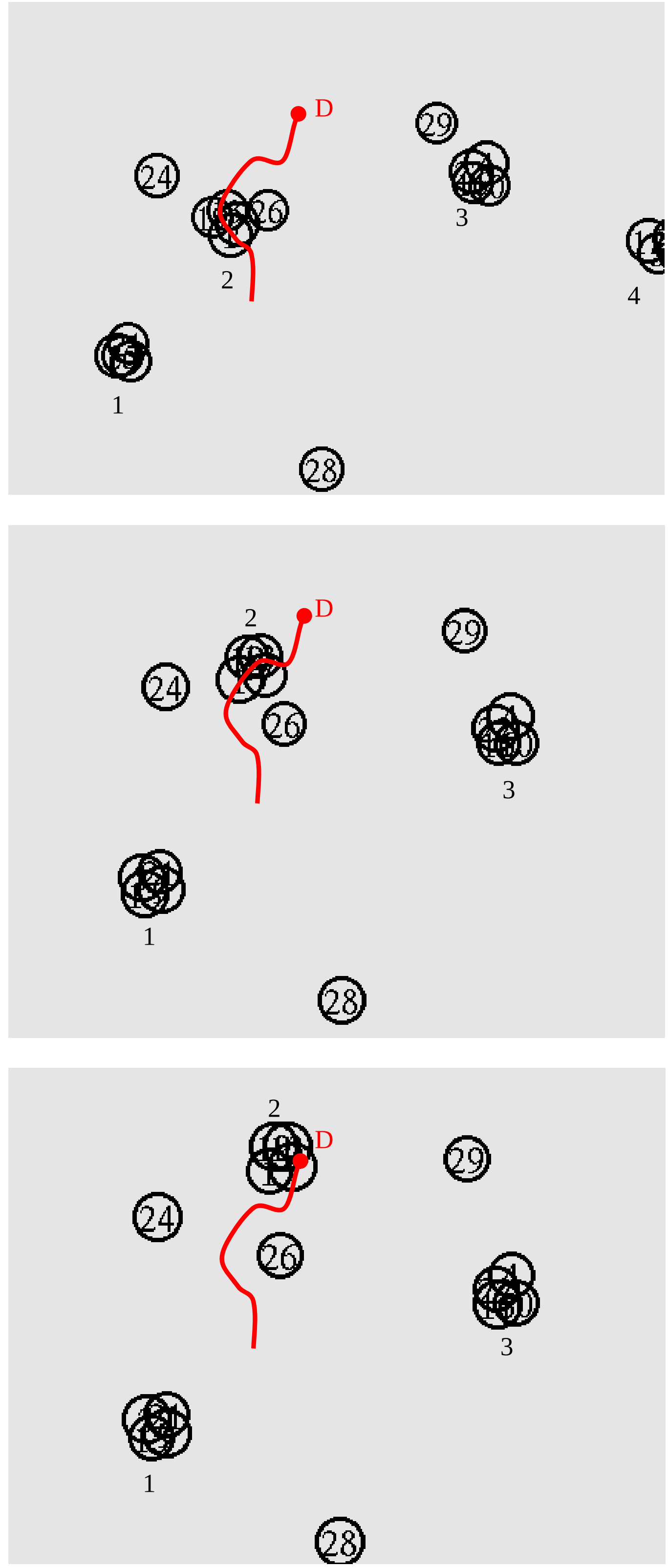

Figure 5. 3 Snapshots of Group Avoiding an Obstacle

at that time instant. In order to establish line-of-sight, the model calculates the equation of the line connecting the two nodes. If the obstacle's center (x,y coordinates) lies on that line or portions of the obstacle intersects this line, then the reachability of those nodes to one another is set to 0. In Figure 6 below, the images shows an example of this line-of-sight approach that is taken to determine if a link can be made between nodes at a specific time instance. Below *n1* and *n2* cannot form a link between each other because obstacle *O* is in the line of sight for the two nodes. However, nodes *n1* and *n3* are reachable and *n2* and *n3* are also.

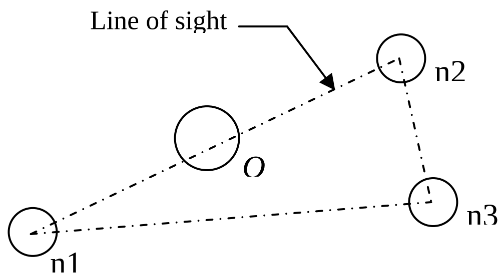

Figure 6. Line of Sight Example

IV. SIMULATION AND RESULTS

The following section discusses the simulation setup and the results of the three GFMMs with obstacles in comparison to RPGM. The performance metrics that were analyze are:

- Link Change
- Link Duration
- Node Degree
- Relative Speed

Because of the increased mobility of the GFMMs and its change in direction to avoid collisions and overlap the initial assumption would be that GFMM will not perform as well statistically as RPGM. However, to design a realistic mobility model this drop in performance is unavoidable. The results will validate these presumptions.

A. Simulation Setup

The parameters are set equally to produce effective and valid performance evaluations. The simulation uses CMU's wireless extension to ns2. This extension uses 802.11 for the MAC layer protocol for Wireless LANs, CSMA/CA for sending data packets, Signal-to-Interference Ratio Threshold for receiving packets, and a radio interface similar to the commercial interface of Lucent's 914MHz DSSS WaveLAN SharedMedia Interface.

Our simulation model (scenario file) was created for the various group force mobility models, Chi-Squared, F, and Rayleigh. For comparative studies, a scenario file was also created for RPGM by executing [12]'s *rpgm* program.

Our conducted simulations contained 60 nodes (10 groups of 6 and 12 groups of 5), 15 obstacles (for GFMM), a pause time of 2.0 seconds, a simulation area of 600m x 400m, a maximum speed of 8 m/s, and a duration of 1200 seconds. The fixed time interval for the three group force models was set to 0.5 seconds.

Details on GFMM, its setup, simulation strategy, code, and additional information can be found at [13].

B. Results

As explained prior, the results were based on certain connectivity metrics used by [12]. The first is Link Changes. It describes the characteristic of a link between two nodes and if it changes from "up" to "down" [2]. It illustrates the stability in the connection between two nodes. The next metric is Link Duration. Obviously, the average time the link between MNs last. The final metrics was Relative Speed. This metric evaluates the relation of speed and direction amongst the nodes.

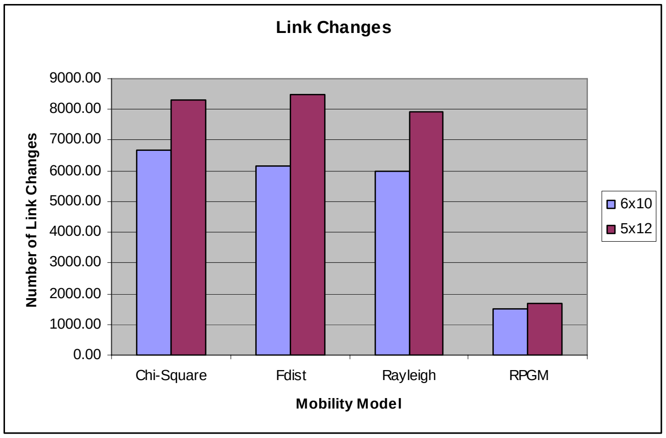

Figure 7. Link Changes

Figure 7 illustrates that the GFMMs had a higher number of link changes than RPGM. This deviation was anticipated. Overall, the increase in the change in direction and the elimination of links due to obstacles in the simulation causes for a higher number of link changes. As explained, an obstacle in the line-of-sight of a MN to another MN will prevent a link from occurring. Consequently, if a link is established between MNs and the movement of either of the nodes causes an obstacle to be in the line-of-sight, then the link will be broken.

In Figure 8, the Link Duration of the various models shows the higher duration for RPGM than GFMMs. Again this is due in part to the changes in the link connectivity between nodes and the high mobility of the GFMMs to change position to avoid collisions and obstacles. This change in position can simply move the node out of communication range.

The relative speed of the node is based on the deviation on velocities between nodes. Initially, because all the models are group-based the speeds will be lower than other models. However, in Figure 9, it is clear that the GFMMs (although group models) experience a high average relative speed than RPGM. As explained in [12] the constant change in direction affects the relative speed values. Therefore, because of the GFMMs avoidance of node and obstacle collision, this metric is higher.

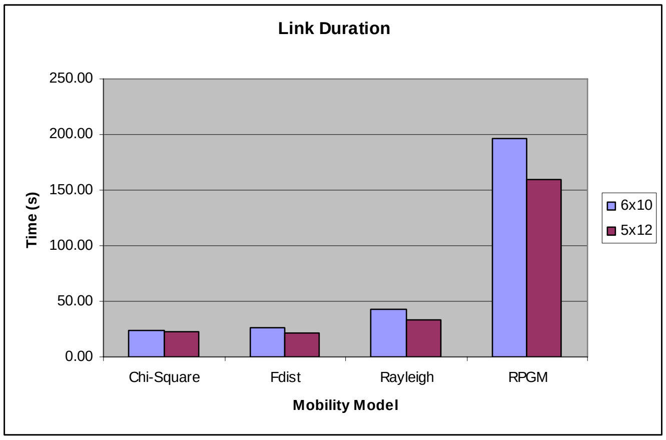

Figure 8. Link Duration

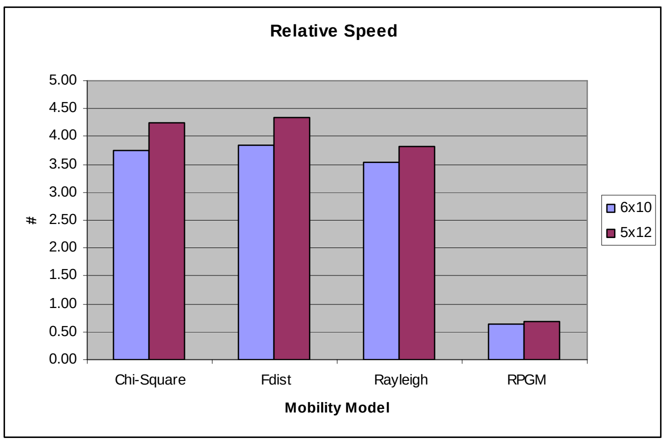

Figure 9. Relative Speed

V. CONCLUSION

In this paper, we revisited the Group Force Mobility Model and how it can be applied to avoid obstacle and other barriers in terrain. This is highly useful for simulation scenarios that account for strenuous and realistic situations as opposed to the open-field methodology. These scenarios include battlefields, college campuses, malls, and everyday activities that exhibit static elements that humans and other entities try to avoid colliding with.

GFMM is designed to be more realistic than most models. It addresses limitations such as collision avoidance with nodes and obstacles and group interaction [2]. Because it focuses on the movement and change in movement of MNs based on the environment, the formation of groups, and the MNs in general, the performance based on connectivity metrics will diminish in comparison to more unrealistic models. The introduction of a force model to dictate the movement and avoidance of MNs and obstacles allows for the GFMM to be applicable to many scenarios.

Our research continues to compare GFMM with some of the most common mobility models to illustrate is importance to research and its significance addressing limitation and to providing realistic simulations. The RPGM is a model which assists academia by introducing group mobility and flow which was compared. It out performed the GFMMs in the connectivity metrics of Link Changes, Link Duration, and Relative Speed. However, this was anticipated do to the lack of adaptability and change of the MNs in a simulation area base on its surrounding. MNs overlapped and did not avoid one another. Also obstacles were not considered which affected connectivity.

Overall, the GFMM has an ability to avoid collision with MNs, obstacles, barriers, and walls base on its force concept. Future research will focus on the change in speed on the MNs based on these forces, the ability for MNs to change groups based on parameters, and increase performance comparisons with other group mobility models.

VI. REFERENCE

[1] X. Hong, M. Gerla, G. Pei, and C. Chiang, "A Group Mobility Model for Ad Hoc Wireless Networks," In Proceedings of *ACM/IEEE MSWiM'99*, Seattle, WA, Aug. 1999, pp.53-60

[2] S. A. Williams, and D. Huang, "A Group Force Mobility Model". Appeared at *9th Communications and Networking Simulation Symposium*, April 2006.

[3] T. Camp, J. Boleng, V. Davies, "A Survey of Mobility Models for Ad Hoc Network Research," Wireless Communication and Mobile Computing 2002.

[4] K. Blakely and B. Lowekamp, "A Strutured Group Mobility Model for the Simulation of Mobile Ad hoc Networks," *MobiWac 2004*

[5] A. Jardosh, E. M. Belding-Royer, et.al, "Towards Realistic Mobility Models For Mobile Adhoc Networks." MobiCom '03

[6] D. Huang, "Using Delaunay Triangulation to Construct Obstacle Detour Mobility Model," in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC)*, pages 1644-1649, Vol. 3, 13-17 Mar 2005.

[7] J. Kristofferson, "Obstacle Constrained Group Mobility Model." Available: http://epubl.ltu.se/1402-1617/2005/306/

[8] P. Johansson, T. Larsson, et.al."Scenario-based Performance Analysis of Routing Protocols for Mobile Ad-hoc Networks" http://db.s2.chalmers.se/download/publications/johansson_493.pdf

[9] D. Helbing, et.al. "Simulating dynamical features of escape panic." *Nature*, 407:487 – 490, September 2000.

[10] C. Gloor, D. Cavens, E. Lange, K. Nagel, and W. Schmid. A pedestrian simulation for very large scale applications. In *A Koch und P Mandl (Hrsg.)(2003): Multi-Agenten-Systeme in der Geographie. Klagenfurt*, 2003.

[11] C. Gloor, P. Stucki, and K. Nagel. Hybrid techniques for pedestrian simulations. In *Proceedings of the 4th Swiss Transport Research Conference (STRC04)*, 2004.

[12] F. Bai, N. Sadagopan, A. Helmy, "Important: a framework to systematically analyze the impact of

mobility on performance of routing protocols for adhoc networks", *in: INFOCOM 2003*.

[13] www.public.asu.edu/~sawilli3/index_files/GFMM.htm.

[14] C. Perkins, E. Royer, S. Das, and M. Marina, *Performance Comparison of Two On-Demand Routing Protocols for Ad Hoc Networks.*. IEEE Personal Communications, February 2001.

[15] S. Gupta, "Performance Evaluation of Ad Hoc Routing Protocols using ns2 simulations". Available: http://www.cs.utk.edu/~gupta/Adhoc.doc.

[16] N. Sadagopan, F. Bai, B. Krishnamachari, and A. Helmy, "PATHS: Analysis of Path duration statistics and their impact on reactive MANET routing protocols", *in: MobiHoc 2003.*

[17] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva. "A performance comparison of multi-hop wireless ad hoc network routing protocols." In *Proceedings of Mobile Computing and Networking*, pages 85–97, 1998.

[18] B. Zhou, K. Xu, and M. Gerla. "Group and Swarm Mobility Models for Ad Hoc Network Scenarios Using Virtual Tracks".

[19] A. Leon-Garcia. *Probability and Random Processes for Electrical Engineering*. Addision Wesley, 1994, pp 102.

[20] Wolfram,Mathword, http://mathworld.wolfram.com/SnedecorsF-Distribution.html

[21] A. Jardosh, E. M. Belding-Royer, K. C. Almeroth, and S. Suri , "Towards realistic mobility models for mobile ad hoc networks," in *ACM MobiCom*, 2003.

[22] D. Helbing, lll´es Farkas, and T. Vlcsek. Simulating dynamical features of escape panic. *Nature*, 407:487 – 490, September 2000.