GROUP AND SWARM MOBILITY MODELS FOR AD HOC NETWORK SCENARIOS USING VIRTUAL TRACKS

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ABSTRACT

The mobility model is one of the most important factors in the performance evaluation of a mobile ad hoc network (MANET). Traditionally, the random waypoint mobility model has been used to model the node mobility, where the movement of one node is modeled as independent from all others. However, in reality, especially in large scale military scenarios, mobility coherence among nodes is quite common. One typical mobility behavior is group mobility. Thus, to investigate military MANET scenarios, an underlying realistic mobility model is highly desired. In this paper, we propose a "virtual track" based group mobility model (VT model) which closely approximates the mobility patterns in military MANET scenarios. It models various types of node mobility such as group moving nodes, individually moving nodes as well as static nodes. Moreover, the VT model not only models the group mobility, it also models the dynamics of group mobility such as group merge and split. Simulation experiments show that the choice of mobility model has significant impact on network performance.

I. INTRODUCTION

Node mobility is one of the inherent characteristics of mobile ad hoc networks (MANET). It is also one of the parameters that most critically affect the performance of network protocols (e.g., routing). Today, in most simulation experiments, node movement is modeled as an independent random walk. One such model is the Random WayPoint Mobility (RWP) model, which is the most popular mobility model used in the literature [1]. However, in real military scenarios, node mobility is not always independent. Mobility correlation among nodes is quite common. One typical example is group mobility. In the battle field, nodes with the same mission usually move in groups such as UAV swarms or tank battalions.

For the modeling of military assets, group mobility models have drawn a lot of interest recently. The mobility models proposed so far in the literature assume some kind of permanent group affiliation. Also they require that each node belongs to a single group. In reality in a typical military scenario, a much more complex mobility behavior is observed. Some nodes move in groups; while others move individually and independently; a fraction of nodes are static. Moreover, the group affiliation is not permanent. The mobile groups can dynamically re-configure themselves triggering group split and mergence. All these different mobility behaviors coexist in military scenarios. A good realistic mobility model must capture all these mobility dynamics in order to yield realistic performance evaluation results, which, unfortunately, is not satisfactorily captured in any of the existing models.

We refer to the non-uniform, dynamic changing scenario described above as "heterogeneous" group mobility scenario. Here, different mobility behaviors such as group motion (including group merge and split), individual motion as well no motion can all coexist. In this paper, we propose a "virtual track" based group mobility model (VT model) which includes all these heterogeneous mobility behaviors. In this model, a certain number of "switch stations" are randomly placed in the field. These stations are all interconnected by "virtual tracks" with given track width. Groups move along the virtual tracks towards the stations. At a station, a group can then be split into multiple groups heading to different stations (e.g. swarming). Groups entering the same station may also merge into one group. The individually moving nodes are then modeled as random moves (using the waypoint model) without the constraint of the virtual tracks. In this paper, we also compare our VT mobility model with other mobility models such as the random waypoint mobility model to investigate the critical impact of mobility models on routing protocols.

The rest of the paper is organized as following. Section II briefly reviews related research in the area of mobility modeling. We then give an overview of the proposed mobility model in section III and the details of the schemes in section IV. Intensive simulation investigation of the mobility model is given in section V and we conclude the paper in section VI.

II. RELATED WORK

The most popular mobility model proposed in the literature for modeling the MANET scenarios is perhaps the Random Waypoint (RWP) model. A node in the RWP model selects a random destination and a random speed between minimum speed and maximum speed, and then moves to the selected destination at the selected speed. Once the node reaches the destination, the node rests for some pause time, and then repeats the process by selecting a new destination, speed and resuming movement [2].

The Random Walk mobility model described in [3] is another popular random mobility model. In this model, each node selects a direction θ in which to move from the range [0...2π]. The nodes select their speeds from a user-defined distribution of speeds, and then each node moves in its select direction at its selected speed. After some randomly chosen period of time or after a specified number of steps, each node halts and selects a new direction and speed. It then resumes movement. The Random Direction model [4] operates similarly to the Random Walk model. The only difference between them is that the nodes in the Random Direction model continue to walk until they are quite close to the simulation boundary. Once they reach this area close to the boundary, they select a new direction in which to walk.

The Reference Point Group Mobility (RPGM) Model [8] is a typical group mobility model. In RPGM model, each node in a group has two components in its movement vector: the individual component and the group component. The individual component is based on the Random Waypoint (RWP) model. A node randomly picks a destination within the group scope and moves towards that destination at a fixed speed. Once the node reaches the destination, it selects another destination randomly and moves towards it after a pause time. This behavior is repeated for the duration of the simulation. The group component of mobility is shared by all nodes in the same group and is also based on the random waypoint model. In this case, however, the destination is an arbitrary place in the entire system. Because the RPGM model is based on RWP model, it still cannot overcome the shortcomings caused by the characteristics of the RWP model, such as non-uniform network density, and it is not adequate to simulate the group movement in reality, such as group split and mergence, etc.

The recently proposed Obstacle Mobility model [9] extends the RWP model through the incorporation of obstacles. These obstacles are utilized to both restrict node movement as well as wireless transmissions. In addition to the inclusion of obstacles, the movement paths between obstacles are also constructed using the Voronoi diagram of obstacle vertices. Nodes can then be randomly distributed across the paths, and can use shortest path route computations to destinations at randomly chosen obstacles. The Obstacle Mobility model is still based on the RWP model which has its intrinsic shortcomings.

The Manhattan mobility model is proposed to model movement in an urban area [10]. In the Manhattan model, the mobile node is allowed to move along the horizontal or vertical streets on the urban map. At an intersection of a horizontal and a vertical street, the mobile node can turn left, right or go straight. The probability of moving on the same street is 0.5, the probability of turning left is 0.25 and the probability of turning right is 0.25. Manhattan mobility model focuses on nodes moving along horizontal or vertical streets, which is not enough to model nodes moving along non-horizontal and non-vertical streets. Moreover, Manhattan model is not suitable to model the movement happening in the intersections of highway systems, which is much more complex than the intersection of local streets.

All existing mobility models don't pay much attention on the group movement and dynamic group split and merge in reality. The VT mobility model proposed in this paper intends to capture various group dynamics. It is a suitable model to simulate the heterogeneous mobility scenario, including group movement, group dynamic split and merge, and individual movement.

III. OVERVIEW OF THE VIRTUAL TRACK BASED GROUP MOBILITY MODEL

The key idea of the proposed model is to use some "virtual tracks" to model the dynamics of group mobility. Some "switch stations" are first randomly deployed in the field. These stations are then connected via virtual tracks with given track width. The grouped nodes must move following the constraint of the tracks. At the switch stations, a group can then be split into multiple smaller groups; some groups may be even merged into a bigger group. Such group dynamics happen randomly under the control of configured split and merge probabilities. Nodes in the same group move along the same track. They also share the same group movement towards the next switch station. In addition, each group member will also have an internal random mobility within the scope of a group. The mobility speeds of these groups are randomly selected between the configured minimum and maximum mobility speeds. One can also define multiple classes of mobile nodes, such as pedestrians, cars, UGVs, and UAVs, etc. Each class of nodes has different requirements: such as moving speed etc. In such cases, only nodes belonging to the same class can merge into a group.

The proposed VT model is also capable to model randomly and individually moving nodes as well as static nodes (such as sensors). Such non-grouped nodes are not restricted by the switch stations and virtual tracks. Instead, their movements are modeled as random moves in the whole field.

Figure 1 illustrates a main idea of the proposed virtual track based group mobility model. In this example, 5 switch stations are randomly placed in the field connected via 8 virtual tracks with equal track width. Group moving nodes are moving towards switch stations along the tracks. They split and merge at switch stations as shown in the figure. The black nodes in Figure 1 represent the individually moving nodes and static nodes. They are placed and move independent of tracks and switch stations.

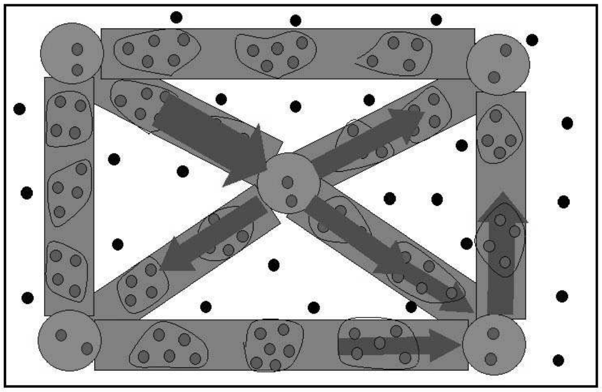

Figure 1 Overview of Virtual Track Based Group Mobility Model

The proposed VT mobility model is suitable for both military and urban environment. In the battlefield, the "switch stations" can be viewed as the gathering points or hot spots of military forces. The virtual tracks are roads or trails or valleys connecting those hot spots. The troops usually move following the predefined track. In the urban environment, the virtual tracks can be viewed as the streets. The switch stations are then the intersections of the streets. In a suburban scenario, the virtual tracks can represent the highways. The switch stations are then viewed as the intersections of the highway. The mobile nodes are then the cars running on the highway (e.g. under the constraint of the tracks). The convoys of cars on the highway can only split at the intersections.

IV. DESIGN OF VIRTUAL TRACK BASED MOBILITY MODEL

4.1 Defining Switch Stations and Virtual Tracks

In the VT mobility model, we first need to define the switch stations and virtual tracks. Initially, the user can specify the number of stations in the scenario. Then the VT model will randomly choose the positions for these stations in the field. Then tracks are defined to connect these switch stations. For simplicity, the user can define a maximum length of the track. Then any two switch stations with distance between them less than this maximum length will be connected by a track. The track width can be user specified or randomly chosen. Of course, to build more realistic scenarios, the users can also specify the positions of switch stations and the tracks connecting these stations.

4.2 Initial Node Distribution and Group Affiliation

After the virtual tracks are defined, we need to distribute nodes during the initialization. The group nodes are initially distributed along the virtual tracks and the individual nodes are initially distributed in the whole field without considering the tracks.

4.3 Group Mobility under Constraint of Tracks

The group mobility is modeled as movements under the constraints of the tracks. Initially, nodes in the same group are placed on the same track. They then select the same switch station at either end of the track as their next destination point. After deciding the destination station, the group as a whole will move towards it. However, this movement is not a straight line to the station. Instead, we model it as random waypoint mobility with two conditions for selecting the intermediate points. The first condition is that an intermediate point must be closer to the destination than previous points. The second condition is that the point must be on the same track. Thus the movement of a group towards a station is simulated step by step moving to some intermediate point on the track closer and closer to the destination. The group movements are applied to all nodes within the group. In addition, each node in the group can also have a small internal mobility under the constraints of the group and tracks. At the switch station, the group can randomly select one track from all other tracks at that station for the next movement.

4.4 Group Split/Merge at the Switch Station

Groups split and merge happen at the switch stations. Each group is defined with a group stability threshold value. When at the switch stations, each node in the group will check whether its stability value is beyond its group stability threshold value. If it is true, this node will choose a different track from its group. A group split happens. When several groups arrive at the same station and select the same track for the next movement, naturally, they will be merged into one bigger group.

4.5 Random and Individual Nodes

In addition to nodes moving as groups, there are static nodes and individually moving nodes. Initially, static nodes are randomly or uniformly distributed within the whole field and have no mobility. Individually moving nodes have random mobility within the whole field without the track constraints. They will be modeled following the RWP model.

V. SIMULATION EVALUATION

5.1 Simulation Platform

The VT mobility model has been implemented in the QualNet network simulator. To evaluate our model, we investigate the performance of the popular routing protocol, AODV [11], under the proposed VT mobility model and the Random WayPoint (RWP) model. Our intention is to observe the performance difference under different mobility models.

The simulation topology is abstracted from a partial LA Highway map. As shown in Figure 2, there are 11 intersections. We take these highways as the virtual tracks, and the intersections as the switch stations, shown in Figure 4. The whole field size is 2200m by 2800m. We simulate 150 nodes which are divided into 4 groups. The traffic is 60 CBR flows with the total offered load of 487.50Kbps.

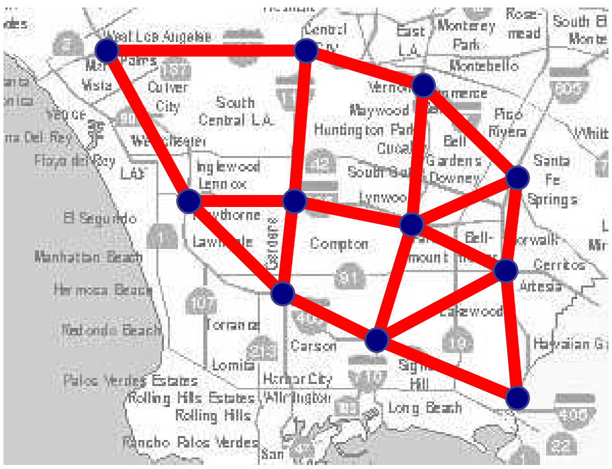

Figure 2. A partial LA highway map

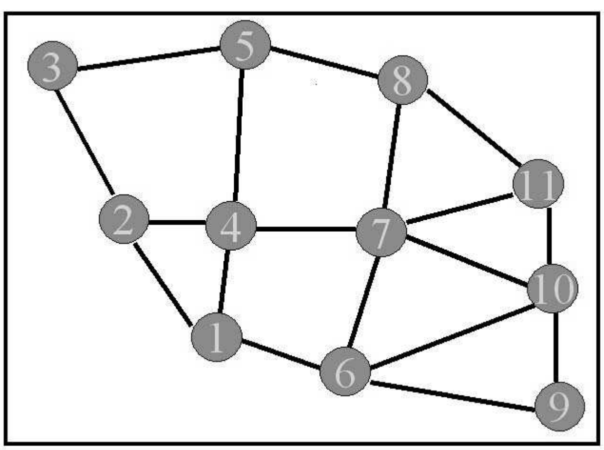

Figure 3. Abstracted topology from LA highway map

5.2 Performance with Mobile Groups Only

The first set of simulations compares the performance of the AODV routing protocol using our VT model versus the Random WayPoint (RWP) model. In this set of simulations of our VT model, no individual nodes are introduced. The maximum speed of a node defines the node mobility.

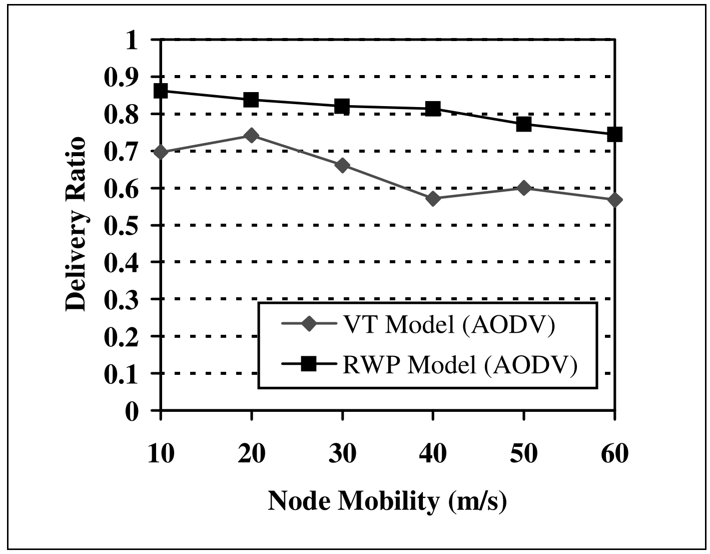

Figure 4. Delivery Ratio vs Node Mobility

The delivery ratio of data packets is shown in Figure 4. The delivery ratio under the VT model is lower than under the RWP model. With the node mobility increasing, the difference of delivery ratio between the two models becomes even bigger.

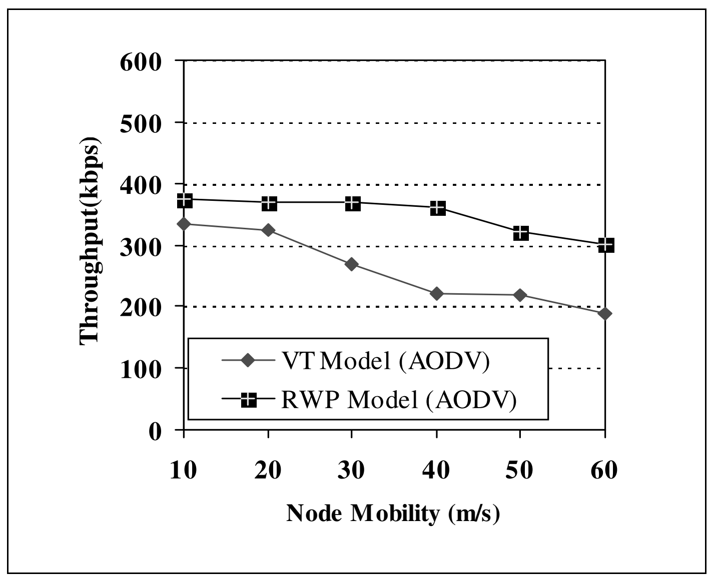

Figure 5. Throughput vs Node Mobility

The aggregated throughput of all flows is shown in Figure 5. Again, the throughput under VT group mobility model is smaller than that under random mobility (RWP model). The throughput applying the VT model decreases rapidly when the node speed increases.

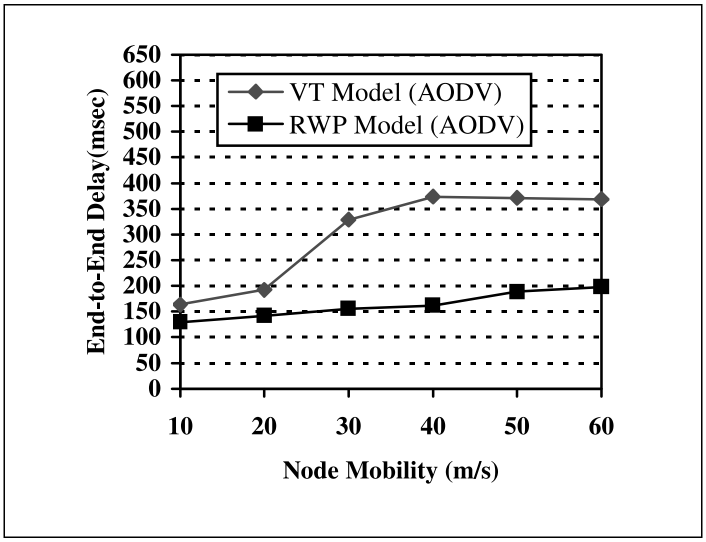

Figure 6. End-to-End Delay vs Node Mobility

Figure 6 shows the End-to-End delay. The End-to-End delay using the VT model is also bigger than that using the RWP model. The delay under the group mobility increases faster than that under random mobility when the node mobility increases.

The above three graphs show that the overall performance under group mobility (as in the VT model) is worse than that under random mobility (as in the RWP model). This is due to the fact that when nodes are moving in groups, the connectivity within a group is strengthened but the connectivity across groups will be typically weaker than the average connectivity when all nodes are uniformly distributed and moving randomly in the space. This implies that using the RWP model when the nodes in reality move in groups will give inaccurate, overly optimistic results.

5.3 Impact of Individual Random Moving and Static Nodes

The second set of simulation experiments studies the performance under VT mobility model with individual nodes and static nodes. In the previous experiments, we observe that group movements may decrease the network connectivity. Now, we will examine whether the individual nodes and static nodes can help maintain rich connectivity among the groups. In this experiment, the total number of nodes is kept as 150. However, a certain fraction of them are individual nodes. The individual nodes can be scattered allover the field. The performance under different fractions of individual nodes is then studied. Three different max speeds of nodes as 40m/s, 50m/s and 60m/s are also studied. The AODV routing protocol is still used as the operational routing protocol.

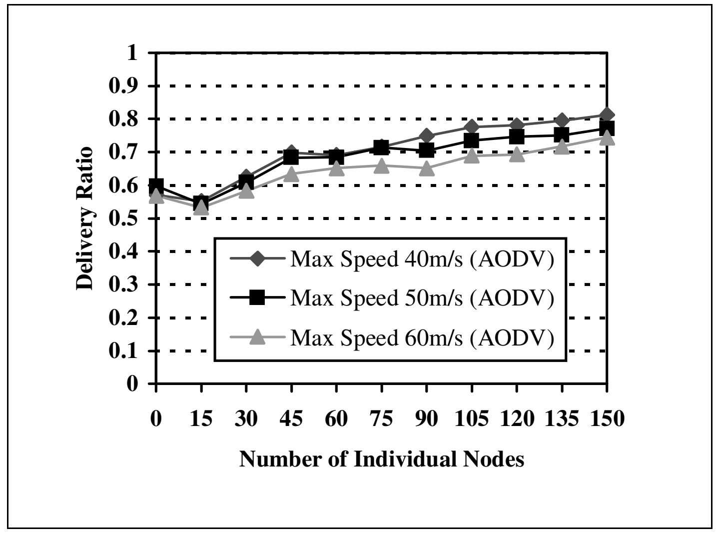

Figure 7. Delivery Ratio vs Number of Individual Nodes

The delivery ratio under different fraction of individual nodes is shown in Figure 7. When more individual nodes are added, the delivery ratio increases. This is consistent under different mobility speeds.

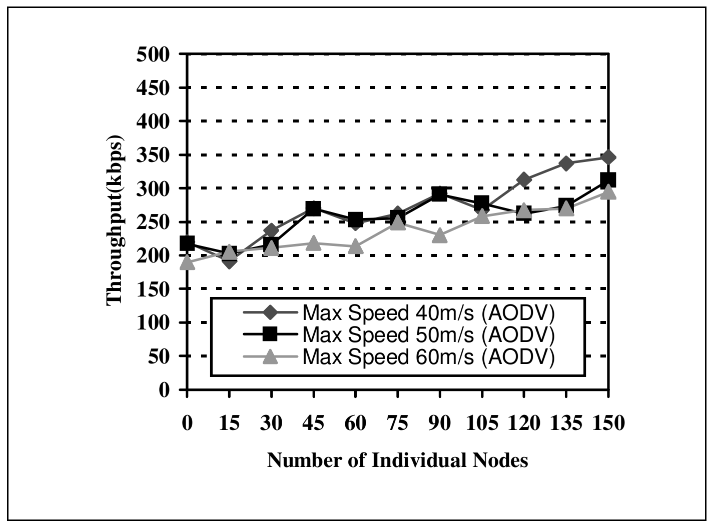

Figure 8. Throughput vs Number of Individual Nodes

The aggregated throughput of all CBR flows is shown in Figure 8. The throughput increases when adding more individual nodes. Although the throughput under max speed of 40 m/s is larger than that under 50 m/s and 60 m/s, the trends of these curves are the same.

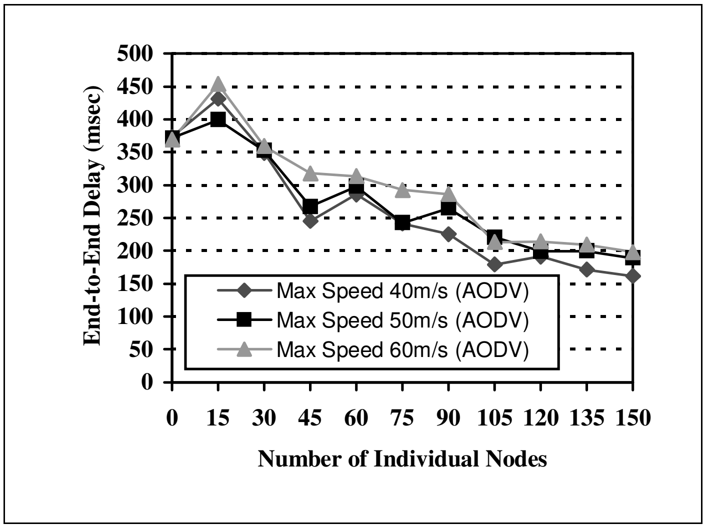

Figure 9. End-to-End Delay vs # of Individual Nodes

Figure 9 shows the End-to-End delay of data packets under different fraction of individual nodes. With the introducing of more individual nodes, the End-to-End delay drops dramatically.

The above three graphs show that the performance of routing protocols under the group mobility model can be greatly enhanced by individual nodes and static nodes. This is not a surprise. When individual nodes are randomly distributed in the field, outside of the "virtual tracks", the connectivity among multiple groups is increased. This implies that in a military scenario with dominant group mobility, deploying forwarding nodes will in general improve the network performance significantly.

VI. CONCLUSION

In this paper, we proposed a Virtual Track based group mobility model (VT model). It is capable to describe "heterogeneous" mobility behavior with group and individual motion; it can also handle static nodes. In order to model group dynamics such as group merge and split, we introduce the concept of "Switch Stations" and "Virtual Tracks". Virtual tracks restrain the movement of grouped nodes along tracks where group mobility is feasible (e.g., highways, valleys, etc). Mobile groups then can split or merge at switch stations. Individually moving nodes and static nodes are also included in the model. They are not constrained by the same routes as group nodes. This diversity makes the VT model a good candidate for modeling realistic military scenarios in our simulation experiments. The simulation results also confirm that mobility models indeed have significant impact on the performance evaluation of network protocols such as routing protocols. Thus, it is essential to use the proper motion model while simulating and testing various network protocols. We expect the proposed VT mobility model will play an important role in simulating emergency recovery and battlefield scenarios where various mobility behaviors typically coexist.

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