Analysis of the Effects of Mobility on the Grid Location Service in Ad Hoc Networks

Chinmay Shete, Salil Sawhney, Supriya Herwadkar, Varun Mehandru, Ahmed Helmy
Department of Electrical Engineering
University of Southern California
{shete, ssawhney, herwadka, mehandru, helmy}@usc.edu

Abstract **-** A Mobile Ad-hoc Network (MANET) is a collection of wireless nodes that cooperatively form a network in the absence of any infrastructure or administration. The grid location service (GLS) is a well-known distributed location service that tracks mobile node locations in ad hoc networks. GLS can be used as a location service in a geographic-based routing protocol to considerably improve the scaling properties of mobile networks. Previous studies of GLS have used the Random Way point (RWP) mobility model for the performance evaluation. While RWP is useful, it may not capture some important mobility characteristics of scenarios where MANETs may be deployed.

In this paper we re-visit the GLS architecture and evaluate its performance over a wide variety of parameter settings and mobility models. We study the behavior of GLS under different mobility models including Freeway, Manhattan and Group mobility models. These models capture interesting mobility characteristics like spatial dependence, temporal dependence and geographic restrictions. Our results show that protocol performance is indeed sensitive to the mobility model. We attribute this significant variance of performance to the interaction between the dynamics of the network connectivity and the protocol mechanisms, and analyze such interaction in our study. One interesting finding is that for group mobility, where node movement is highly correlated and location discovery is conceivably simpler, the performance of GLS in fact degrades instead of improving. This different behavior for group mobility points to a subtle interaction and deeper coupling between the mobility model and the underlying grid.

1. Introduction

A Mobile Ad-hoc Network is a collection of wireless nodes that cooperatively form a network and communicate with each other in the absence of any infrastructure or administration. The various scenarios that could benefit from an ad-hoc network creation include search and rescue operations, disaster relief, wireless classrooms, and law enforcement. The Grid Location Service (GLS) [1] describes a system called as the GRID that combines cooperative infrastructure with position information to enable routing in large scale ad-hoc networks. Research has shown that GLS can be used as a location service in a geographic –based routing protocol to considerably improve its scaling properties. Also it has been shown that mobility significantly affects the performance of MANET routing protocols [2]. Along with mobility the communicating traffic pattern also influences the performance of routing protocols. To date all simulations for GLS have used RWP (Random Waypoint) model for mobility. In this paper we conduct a parameter-rich study to evaluate GLS for various mobility models. We study the behavior of GLS under different mobility models such as the Freeway, Manhattan and Group mobility models. The use of various different mobility models encompasses scenarios where there exists spatial dependence among nodes, temporal dependence of movement over time and also existence of barriers and obstacles constraining mobility. Capturing these characteristics of mobility is often ignored in work on location-based routing, and distinguishes our work from previous work in this area. The metrics used to describe the affect of mobility and node density include throughput and overhead (in terms of the number of update packets sent). We conduct a detailed analysis of performance over various mobility models over a wide range of velocities.

Among our observations is that RWP does not exhibit the worst-case performance of GLS. Another interesting finding is that the group mobility model exhibits trends that are quite different from the other mobility models. The rest of our observations are specific to the comparison metrics used and highlight various important aspects regarding the various mobility models and their behavior under various simulation conditions and overall impact on the routing protocol. In all, our study shows that the performance of GLS is sensitive to the mobility parameters, and that a parameter-rich evaluation of GLS is needed to understand its performance.

The rest of the paper is outlined as follows. Section 2 discusses related work on GLS and mobility models. Section 3 describes the evaluation metrics and method, and the simulation setup. Section 4 presents and discusses the results and our analysis. Section 5 summarizes our conclusions and the future work planned.

2. Related Work and Background

GLS: The Grid Location service (GLS) [1] is a service that tracks the location nodes in a Mobile Ad hoc network (MANET). GLS enables the construction of a scalable MANET as it uses stateless greedy geographic forwarding. Each node maintains its current location in a certain number of location servers distributed throughout the network. A node may act as a location server for others and the location servers for a particular node are relatively dense close to the node and sparser away from the node. A grid-based hierarchy is used to define nodes acting as location servers. Each node is assigned a unique ID. A consistent hashing technique is used to choose location servers. A source node forwards queries to the node with smallest ID greater than or equal to the destination node ID. Once the destination location is obtained, greedy forwarding is used to send data to the destination. Related research work on GLS was presented in[3,4]. The original simulations have been done using only

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the RWP mobility model. What is lacking in the work is the comparison with the behavior of GLS across different mobility models. Secondly the work in [3] introduced a classification of the dropped packets and update packets as being of various types and occurring due to different reasons. We adopt such classification in our study. However having only considered RWP model in previous studies the significance of the classification was not fully appreciated. Here, we develop a framework for evaluation of GLS over various mobility models.

Recent research in [2][5] demonstrates the importance of using mobility patterns other than RWP for proactive/reactive ad hoc routing protocols. The coupling and interaction of geographic routing (e.g., GLS) with various mobility models has not been studied before. Our results show an inherent coupling between GLS, the network grid, and the underlying mobility model that was not observed before.

Mobility Models: The Random Waypoint (RWP) model is one commonly used mobility model. *IMPORTANT* [2] describes the *Freeway*, Group (*RPGM*) and *Manhattan* mobility models that we adopt in our study. Each of these models captures mobility characteristic not captured by RWP.

1. In **RPGM** each group of nodes has a group leader that determines the group's motion. Initially, group members are uniformly distributed near the leader. Within one group, each node's velocity deviates slightly from that of the leader. The speed (V) and angle (θ) are set as follows.

$$|\vec{V}_{node}(t)| = |\vec{V}_{leader}(t)| + random() \times SDR \times V_{\max}$$

$$\theta_{node}(t) = \theta_{leader}(t) + random() \times ADR \times \theta_{\max}$$

In our study, we take *SDR*=*ADR*=0.1.

2. In the **Freeway Model** each mobile node is restricted to its lane on the freeway and the velocity is temporally dependent on its previous velocity. If two mobile nodes on the same freeway lane are within a Safety Distance, the velocity of a node cannot exceed the velocity of its preceding nodes. Due to the above relationships, the Freeway mobility pattern is expected to have high spatial and temporal dependence. It also imposes geographic restrictions on the node movement by not allowing a node to change its lane, for example.
3. In the **Manhattan Model** nodes move on streets defined by a map composed of a grid of horizontal and vertical streets with two lanes in opposite directions. At an intersection the node can turn left or right with probability 0.25 or go straight with probability 0.5. Velocity of a node at a time depends on its previous velocity and that of nearby nodes as in the Freeway model. Thus, the Manhattan mobility model is also expected to have high spatial and temporal dependence.

3. Evaluation Framework of GLS

We analyze the performance of GLS under varying node mobility conditions by changing node velocity, and mobility patterns using RWP, Freeway, Manhattan and RPGM mobility models. Specifically, we observe the effect of mobility on throughput and protocol overhead. Throughput is the fraction of sent packets that are received successfully. Protocol overhead is the number of control packets generated (expressed as a fraction of the total number of packets in the simulation). Also, we analyze the query success rate and various types of *update* and *dropped* packets to analyze the interplay between mobility and protocol mechanisms.

Update Packets: The two main types of update packets are (I) crossing (*XING*) and (II) distance (*DIST*). A node sends *XING* packet when it crosses the current order square to a higher order square, and sends *DIST* packet when it crosses a predefined distance threshold (100m).

Dropped Packets: Packet drop can be due to various reasons. A No-Route (*NRTE*) drop means that greedy forwarding in GLS can not find any other node closer to the destination and simply drops the packet. A Time-to live (*TTL*) drop occurs when the packet travels for long in the network causing *TTL* to expire. The *RLOOP* drop occurs when a loop is detected, e.g., when the packet returns to its source. *IFQ* refers to a drop at the network interface queue due to contention.

Comparison across the above mentioned mobility models was carried out to determine performance of GLS under different mobility scenarios, such as determining scenarios for which GLS has low overhead and high throughput.

Simulation Environment

We used the network simulator *NS-2* [7] version 2.1b8a with the CMU wireless extensions[6] and the GLS code[3]. For mobility we used the *IMPORTANT* [2] mobility tool. Simulated area was 1kmx1km. The radio range was set to 250m. For RWP the pause time was set to zero, and for RPGM we used a single group. Node velocity was varied from 5-60m/s, keeping node density at 40 nodes/km^2. CBR traffic was used for 32 connections and a rate of 4pkts/sec. Each simulation was run 3 times with the averages recorded.

4. Results and Analysis

In this section we present the results of our simulations. For brevity, we show only the most important results. Sections 4.1 and 4.2 provide GLS performance results in case of the Manhattan, Freeway and RPGM models. Section 4.3 provides results for the query success rate, while Section 4.4 provides comparative results.

4.1 GLS with Manhattan and Freeway Models

The velocity, *Vmax*, was varied between 5-60m/s. Throughput and protocol overhead was measured, and the update and dropped packets were traced and analyzed.

Throughput: For Manhattan and Freeway models the throughput reduces with increase in velocity. This is due to an increase in the relative velocity between nodes, which in turn leads to reduced link and path duration. Path breaks lead to packet drops and reduced throughput. The packet drop continues until GLS converges on a new valid route. The drop is found to be greater in case of the Freeway model.

Protocol Overhead: For both Manhattan and Freeway models the overhead increases with increase in velocity, because route breaks trigger GLS route recovery and update packets.

Types of Update Packets: The number of *XING* and *DIST* packets increase with velocity (Fig 1). This is expected as the function of these packets is to update location information when the node moves. The number of *DIST* packets is more than the number of *XING* packets. This is because the probability of nodes crossing the threshold distance is higher than crossing their current order square.

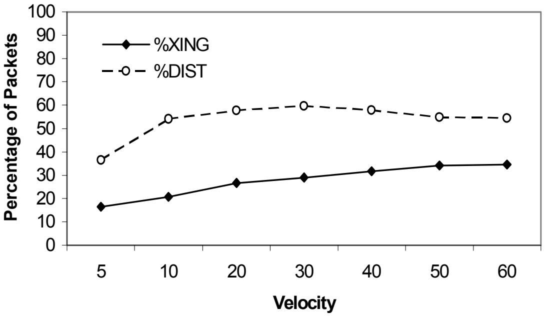

Fig 1. Percentage update packets for GLS with Manhattan mobility

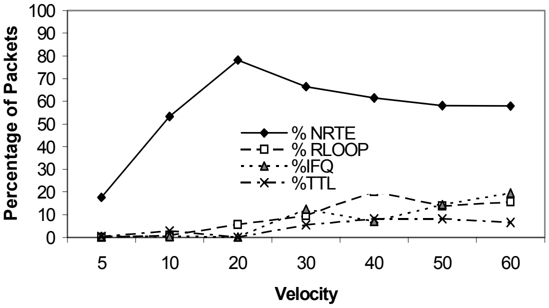

Fig 2. Percentage dropped packets for GLS with Manhattan mobility

Types of Dropped Packets: For both models the number of *NRTE* drops is the highest (Fig 2). This is due to (i) the high frequency of route breakage because of low link duration and (ii) relatively low density with 40 nodes. Low link duration is due to the fact that Manhattan and Freeway mobility models incur the highest relative velocity among the mobility models investigated [2]. One thing to note is that number of *RLOOP* and *TTL* drops gets higher with higher velocity, though *NRTE* dominates due to low node density. With increase in velocity the possibility of forming loops increases, leading to more *RLOOP* and *TTL* drops. *RLOOP* drops occur more than *TTL*.

4.2 GLS with Group Mobility

We evaluate GLS with the reference point group mobility (RPGM), using a single group scenario. Again, the maximum velocity, *Vmax*, was varied from 5-60m/s. The RPGM model exhibits the maximum spatial correlation between nodes and has the highest link duration [2]. Hence, we expected GLS to perform better, as it is intuitively easier to maintain relative locations between the nodes due to the very low relative velocity. Based on our results, the behavior of GLS did not follow our expectation, which pointed to an interesting interaction between group mobility and GLS.

Throughput: We find a major difference in the GLS performance when considering the group mobility model. The throughput is near perfect with velocity (Fig 3). The primary reason for this is the amount of spatial dependence in Group mobility model. Hence even though the group moves at a particular velocity there is a very low relative velocity amongst the nodes and hence the network as a whole is (relatively) almost static, with extremely low probability of a route being broken due to different velocity directions.

Protocol Overhead: This is found to be between 20-25% with increasing velocity (Fig 4). Once again, the GLS performance is different as compared to the previous scenarios where overhead was found to increase with velocity. However, the overhead incurred for RPGM is much higher than the overhead incurred for the other mobility models. We shall re-visit this interesting point in Section 5.6.

Types of Update Packets: In this case too the Group mobility model behaves differently. Having kept the deviation parameter for the group low (*SDR*=*ADR*=0.1), the correlation between node movements is high. Since the nodes move in a group, when a node crosses from a lower order grid square to a higher one, the probability of other nodes in the group following suit is high. Hence if one node produces a *XING* packet, other nodes will too. Hence, the fraction of *XING* compared to *DIST* is higher than in other models (Fig 5).

Types of Dropped Packets: In this case, the percentage of *NRTE* packets is again the highest. However the percentage is close to 95% as the contribution due to other drop packets such as *TTL* and *RLOOP* is much lower (Fig 6). This is because the possibility of routing loops forming and the *TTL* field expiring are low in the case of RPGM. Overall, the number of dropped packets in RPGM is quite low due to the high correlation between nodes with very high link duration.

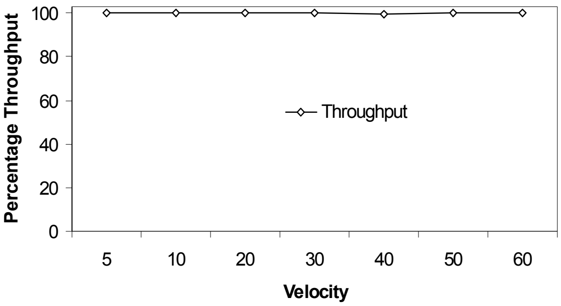

Fig 3. Percentage Throughput for GLS with RPGM

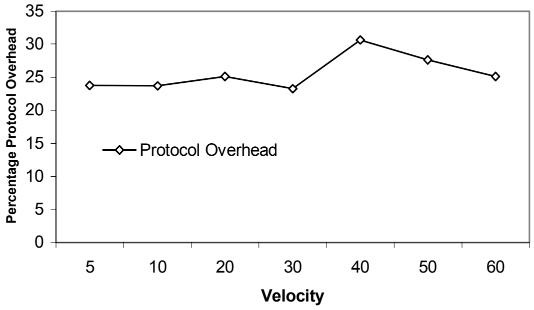

Fig 4. Percentage Protocol Overhead for GLS with RPGM

4.3 GLS Query Success Rate

In this section we analyze the performance of GLS in terms of the location query success rate. First, we tested the query failure rate across different mobility models including RWP for a node density of 40nodes/km^2 and *Vmax*=10m/s. Second, we observed within each model the effect of velocity on the failure rate. We observed that the RWP showed the least failure rate (3%) and Group model showed the highest failure rate (38%). This has two very important implications: (i) RWP is *not* the worst case model, (ii) it is quite interesting to observe that Group mobility has the highest throughput for CBR traffic but the highest query failure rate as well.

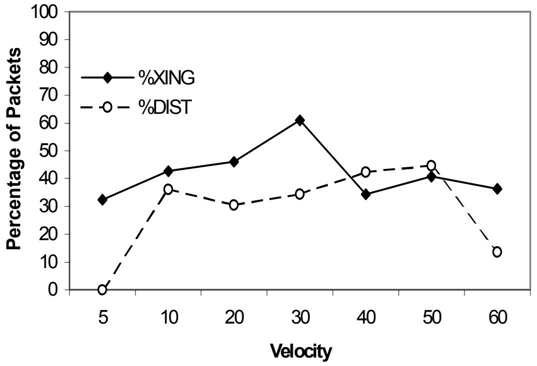

Fig 5. Percentage update packets for GLS

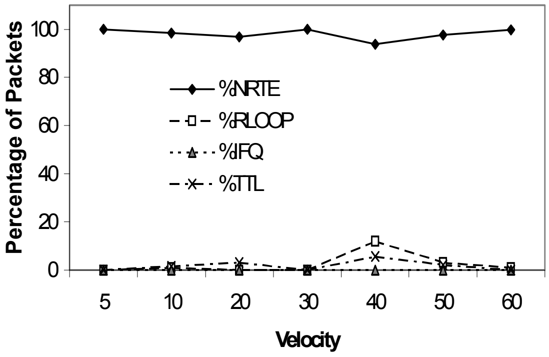

Fig 6. Percentage dropped packets for GLS

To understand the reason for this behavior we must first identify why a query fails. A query fails when a node moves far away from its previous location rendering the cached location (in the location servers) invalid. Even though update packets are sent to remedy this situation, the timing of those updates, or the movement of the servers may prolong the protocol convergence time. If this occurs frequently then the query success rate will likely decrease.

In RPGM, the movements of all the nodes (the target node and the servers) are highly correlated. Hence, the scenarios created by the simultaneous mobility of the nodes in a coordinated fashion prolong the protocol convergence time. This in turn leads to a higher query failure than in other models, where this correlated movement is not as strong.

Note that the important feature of RPGM for the query failure rate was not the higher link duration, but it was the dynamics of the relative movement of the nodes (including the location servers) with respect to the grid structure. For throughput, on the other hand, once the query succeeds then the obtained path is valid for a longer time due to the high correlation between nodes. Hence, the important feature for throughput is the spatial correlation between nodes.

For all mobility models the query success rate decreases with an increase in node velocity. This is due to the increase in the number of route breakages with increasing velocity.

4.4 GLS across Mobility Models

In this section, we attempt to take a more comprehensive look at the results and compare the results across the different mobility models. This allows us to point out differences in trends and facilitates reasoning about the observed behavior. When comparing across the various mobility models the maximum node velocity, *Vmax*, was kept at 60 m/sec.

Throughput: The data packet throughput for GLS is maximum with the RPGM model (Fig 7). This is due to the high degree of spatial dependence between nodes that leads to reduced route breaks. The worst throughput was exhibited for the Manhattan model, because it has the highest relative velocity and lowest link duration statistics. This observation is consistent with the work on the performance of DSR's throughput across mobility models [2].

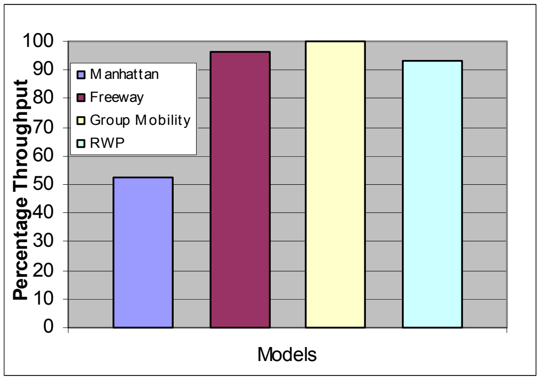

Fig 7.Throughput across different Mobility models

Protocol Overhead: The protocol overhead for GLS with RPGM is the highest (Fig 8). As mentioned earlier, there is a subtle coupling between the correlated node movement due to the mobility model and the underlying grid. This is explained as follows. In RPGM, when all the nodes move together and cross grid boundaries together, a large protocol overhead in terms of GLS update packets is incurred. Due to the very high node movement correlation in RPGM, this overhead is significantly larger than the overhead incurred with the other mobility models with lower spatial correlation.

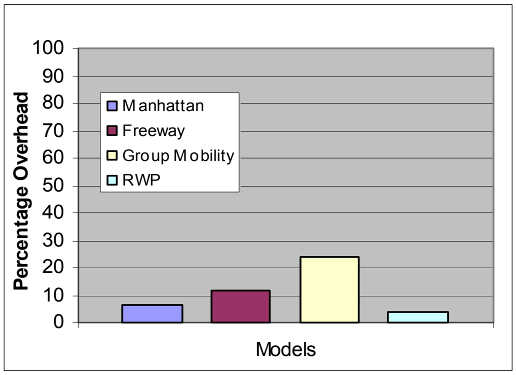

Fig 8. Protocol Overhead across different Mobility models

Note that this result is *inconsistent* with related observations on behavior of routing protocols (e.g., DSR) across mobility models in [2]. In that study the group mobility incurred the *least* overhead. This points out that the observed behavior is not only due to the mobility model, but also due to the interaction and interplay between the mobility model (affecting network connectivity *and* node locations) and the protocol mechanisms.

Percentage of Update packets: The highest percentage of *XING* packets is triggered with RPGM, because when a node moves to a higher order square and sends a *XING* packet the probability of another node sending *XING* is high (Fig 9). All mobility models, compared to RPGM, result in higher percentage of *DIST* packets as nodes cross threshold distance more often than crossing to higher order square (Fig 10).

Percentage of dropped packets: The percentage of *NRTE* packets is highest in the case of group mobility as contribution from *RLOOP* and *TTL* is ~'0' (Figs 11 and 12).

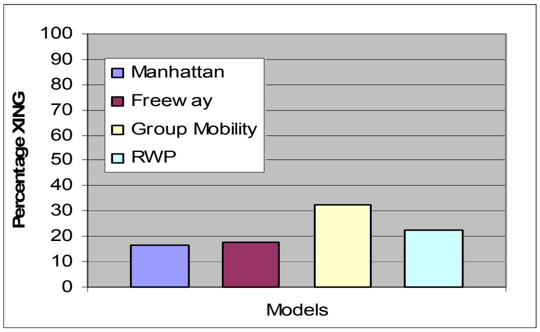

Fig 9. Percentage *XING* across different Mobility models

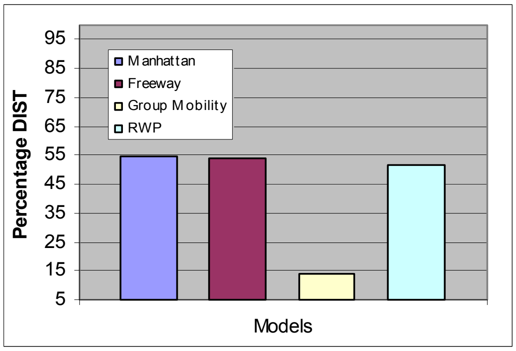

Fig 10. Percentage *DIST* across different Mobility models

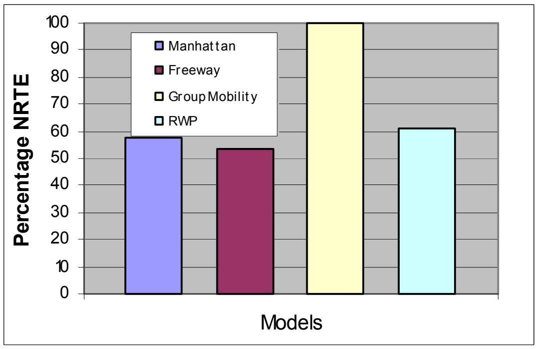

Fig 11. Percentage *NRTE* across different Mobility models

5. Conclusion and Future Work

In this paper we have studied the performance of GLS across different mobility models including Random Way Point, Freeway, Manhattan and Group mobility models. We find that the performance of GLS does vary significantly for different mobility scenarios. For RWP, Manhattan and Freeway mobility models we observe that throughput decreases and protocol overhead increases with increasing velocity. With group mobility was used the throughput remains very high unaffected by velocity due to high correlation between node movements. The proportion of GLS update and dropped packets was different for RPGM as compared to RWP, Manhattan, Freeway models. GLS incurred the maximum overhead with the group mobility. This pointed out a subtle coupling between the mobility model and the underlying grid in GLS. Another interesting result is that GLS with RPGM (not RWP) experienced the worst query success rate due to prolonged convergence time.

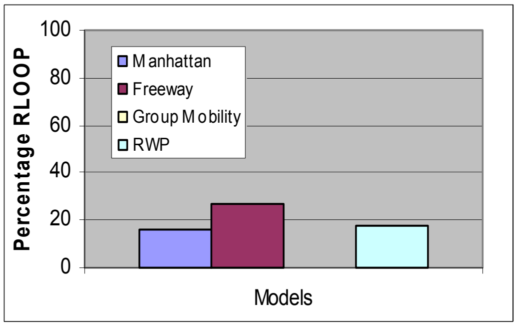

Fig 12. Percentage *RLOOP* across different Mobility models

The main contributions of our paper may be summarized as follows. First, this is the first in-depth study of a location distribution service (*GLS*) under various mobility models. The study clearly shows, qualitatively, the sensitivity of GLS to mobility. Second, our results show that for GLS the conclusions are not always consistent with other mobility studies for other ad hoc routing protocols, even for the same mobility models and the same movement traces. This last remark inspires what we consider to be the major contribution of this paper: *In order to understand the protocol behavior with mobility, we must understand and characterize (a) the mobility models, (b) the protocol mechanisms, and (c) the interaction and interplay between the protocols and mechanisms.*

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