Performance Comparison of Geocast Routing Protocols for a MANET*

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Abstract – This paper classifies the current geocast routing protocols of a Mobile Ad hoc NETwork (MANET) into three categories. We then simulate a typical geocast routing protocol in each category. As far as we are aware, this paper is the first to compare several geocast routing protocols for a MANET. We performed four studies designed to highlight the various strengths and weaknesses of the protocols: node density, traffic/congestion, mobility, and a combination study examining all three parameters together.

1 Introduction

An ad hoc network is a set of wireless mobile nodes (MNs) that cooperatively form a network without specific user administration or configuration. Geocasting, a variant of conventional multicasting, distinguishes itself by defining the destination nodes to be any node that happens to be within a specified geographical region, i.e., the geocast region. To determine the geocast group membership in a MANET, each node is required to know its own physical location, i.e., its geographic coordinates, which may be obtained using a system such as the Global Positioning System (GPS).

Three categories of geocast routing protocols have been developed: flooding-based, routing-based and cluster-based protocols. Flooding-based protocols use flooding or a variant of flooding to forward geocast packets from the source to the geocast region. Protocols in this category include Location-Based Multicast (LBM) [6] and the Voronoi diagram based geocasting protocol [10]. Routing-based protocols create routes from the source to the geocast region via control packets. Protocols in this category include the Mesh-based Geocast Routing Protocol (MGRP) [1], Geocast Adaptive Mesh Environment for Routing (GAMER) [3] and GeoTORA [5]. Cluster-based protocols geographically partition a MANET into several disjointed and equally sized cellular regions and select a cluster head in each region for executing information exchange. Protocols in this category include GeoGRID [7], Obstacle-Free Single-Destination Geocasting Protocol (OFSGP) and Obstacle-Free Multi-Destination Geocasting Protocol (OFMGP) [4]. For more details on these protocols, see [11].

To obtain a condensed but comprehensive side-by-side comparison, we simulated a typical protocol in each of the three geocast routing protocol categories. We performed four studies designed to highlight the various strengths and weaknesses of the protocols: node density, traffic/congestion, mobility, and a combination study examining all three parameters together.

2 Geocast Protocols

We chose to evaluate LBM [6] for flooding-based protocols because LBM is the most referenced geocast routing protocol. We selected GAMER [3] from the routing-based protocol category because GAMER was developed by our research group. We chose GeoGRID [7] for cluster-based protocols because only GeoGRID does not considered obstacles in this category.

2.1 Flooding-based geocast protocol: LBM

The Location-Based Multicast (LBM) protocol [6] reduces the forwarding space of geocast packets. A node forwards a geocast packet only if it belongs to the forwarding zone or to the geocast region. Once a packet reaches the geocast region, it is flooded within the geocast region. Two forwarding zone schemes (box and step) are defined for LBM [6].

We implement LBM-box with an adaptive zone [6]. With an adaptive zone, LBM-box defines the forwarding zone to be the smallest rectangle that includes the current location of the intermediate node and the geocast region. Thus, as shown Figure 1 (which is a figure similar to a figure in [6]), the forwarding zone is adapted at any intermediate node. LBM-step (which is always adaptive) defines the forwarding zone to be the smallest circle centered at the geometrical center of the geocast region that includes the intermediate node.

LBM provides additional control on the size of the forwarding zone by a parameter $\delta > 0$ [6]. In LBM-box, the forwarding zone is extended such that each side of the forwarding zone is δ larger than the minimum necessary to include the intermediate node. Likewise, in LBM-step, the radius of the forwarding zone is δ larger than necessary.

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2.2 Routing-based geocast protocol: GAMER

Geocast Adaptive Mesh Environment for Routing (GAMER) [3] provides a mesh of paths between the source and the geocast region. When a link breaks due to the changing topology in an ad hoc network, the redundant paths that exist in the mesh can be used. The mesh is created by flooding JOIN-DEMAND (JD) packets within a forwarding zone. Once a node in the geocast region receives a non-duplicate JD packet, it generates a JT packet and unicasts it back to the source following the reverse route taken by the JD packet. All of the nodes in the reverse route become parts of the mesh. Data packets generated by the source are forwarded by the mesh members within the mesh and flooded within the geocast region.

GAMER dynamically changes the density of the mesh by choosing a Forwarding Approach (FA) to keep the network load as low as possible. A source node can choose among CONE, CORRIDOR and FLOOD FAs. Figure 2 (which is a figure similar to a figure in [3]) shows examples of meshes created with the CONE, CORRIDOR and FLOOD FAs. GAMER adapts its FA to a smaller one if the current FA succeeds, or a larger one if the current FA fails.

2.3 Cluster-based geocast routing protocol: GeoGRID

In GeoGRID, the geographic area of the MANET is partitioned into 2D logical grids. In each grid, one node is elected as the gateway of the grid. Thus, instead of having every node forward data, only gateway nodes forward data. In [7], the authors propose two versions of GeoGRID: flooding-based GeoGRID and ticket-based GeoGRID.

In the flooding-based approach, each gateway within the forwarding zone (the smallest rectangle including the source when it sent the packet and the geocast region) will rebroadcast the received geocast packets. For example, in Figure 3 (which is a figure similar to a figure in [7]), gateway I discards the geocast packet as it is not in the forwarding zone; all others retransmit the packet exactly once.

In the ticket-based approach, intermediate nodes transmit the geocast packet only if they receive a ticket(s). Each node receives zero or more tickets, so not all nodes in the forwarding zone are allowed to retransmit. Once the packet reaches the geocast region, it is flooded among the gateways.

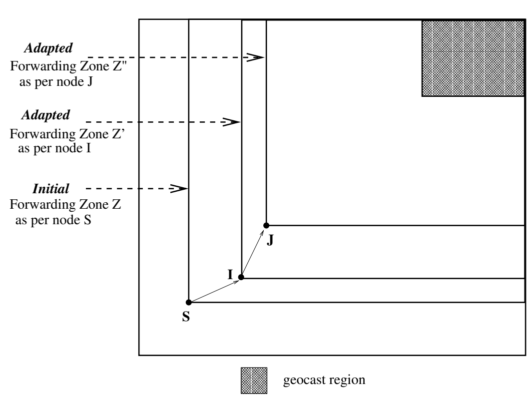

Figure 1: LBM-box with an adaptive zone: the forwarding box is adapted at each intermediate node.

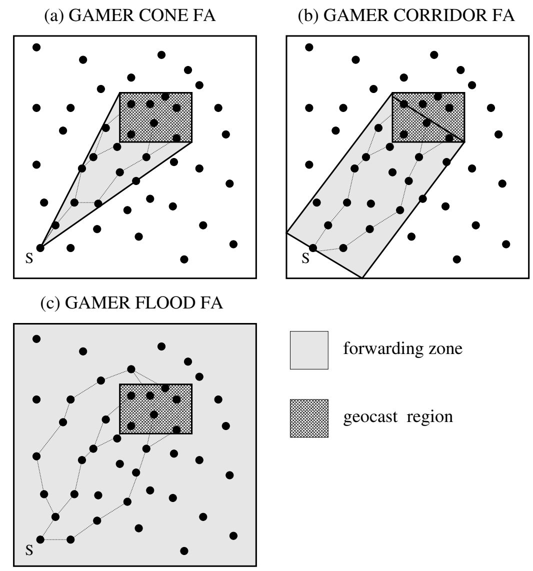

Figure 2: GAMER: Mesh created in CONE, CORRIDOR and FLOOD.

For both versions of GeoGRID, when a gateway needs to be elected, the mobile node nearest to the physical center of the grid is elected. When a gateway moves out of the grid, a new election occurs.

3 Protocol Implementations

3.1 LBM implementation

We set δ for both LBM-box and LBM-step to 0. We implement the LBM-box with adaptive zone [6] (see Section 2.1 for detail). We developed the simulation code for LBM.

3.2 GAMER implementation

In [3], the authors propose two versions of GAMER: Active GAMER and Passive GAMER. In Passive GAMER, JOIN-DEMAND (JD) packets are sent with a fixed frequency. In Active GAMER, JD packets can also be sent in response to JD packet failures. Since Active GAMER is more active in increasing the size of its forwarding zone [3], we simulate Active GAMER in this paper.

In [1] and [3], the authors use source routing in the mesh creation. However, to avoid the overhead caused by storing path information in every JD packet header, nodes maintain local routing tables instead of source routing in our simulation. In other words, the intermediate nodes on a JD packet path maintain routing state in our modification of the Active GAMER simulation code.

There are three parameters in Active GAMER: the JD packet interval, the mesh-member timeout and SWITCH-

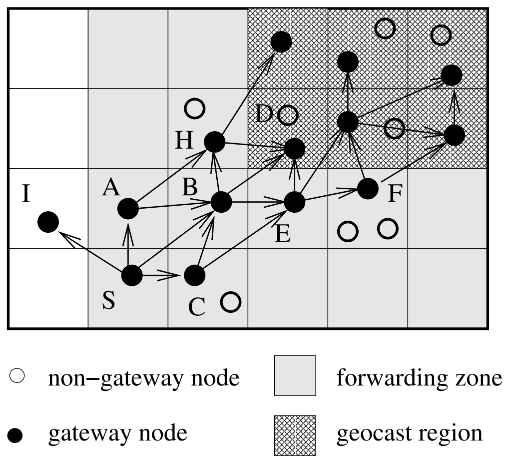

Figure 3: Flooding-based GeoGRID. All gateway nodes that are in the forwarding zone retransmit.

TIMER. The JD packet interval parameter is the interval in which the source floods JD packets. The mesh-member timeout parameter defines the lifetime of a mesh member. SWITCH-TIMER is the timer for the adaption to a larger FA, if possible. We chose 1 second for the JD packet interval, 3 seconds for the mesh-member timeout, and 0.2 seconds for SWITCH-TIMER.

3.3 GeoGRID implementation

There are three anomalies that caused our GeoGRID code to differ from that suggested by the authors. First, we do not send GATE packets (which announce an election gateway) periodically. Periodic GATE packets are useful for spontaneous node failure, which we do not simulate. Second, we restrict all nodes to send exactly one BID packet (which announces a bid to be a gateway) per election rather than one per BID packet received. This modification had no effect on the performance of the protocol other than to reduce overhead. Third, every 300 ms (not continuously), a node checks whether it has left the grid.

We developed the simulation code for both flooding-based GeoGRID and ticket-based GeoGRID. We found the ticket-based version of GeoGRID suffers from a number of problems. In our simulations, it was rare if tickets reached a geocast region three grids away. Due to such poor performance, results for ticket-based GeoGRID are not provided in Section 5.

For flooding-based GeoGRID, we used a grid size $d = \frac{\sqrt{2}}{3}r$ where r is the transmission radius. We finalized gateway elections 2 ms after the last BID transmission.

4 Simulation Environment

The geocast protocols are implemented in the network simulator NS-2 [9]. The simulation area is a 300 x 600 meter rectangle. The geocast region is a 150 x 150 meter square located in the upper right corner. We put one static node in the center of the geocast region, i.e., location (225, 525) to ensure that at least one node resides in the geocast region to receive the geocast packets transmitted. Each Mobile Node (MN) in the network has a uniform transmission range of 100 meters, and the link bandwidth available for each MN is 2 Mbps. In each 1000 seconds simulation period, the single Constant Bit Rate (CBR) source generates 64-byte geocast data packets. We jitter the scheduling of sending packets by some uniform random amount of time to avoid unnecessary collisions.

The nodes move according to the random waypoint mobility model [2]. In this model, nodes repeatedly select uniform random destinations, move to them, and pause there. We initialize the locations and pause times of the MNs with the steady state distribution for the random waypoint mobility model (i.e., mobgen-ss) [8]. Thus, we avoid the initialization problem of the random waypoint mobility model which is discussed in [12].

All of our simulation trials are initialized without partitions and execute long enough to ensure that all the transmitted packets either reach the geocast region or expire. To allow time to build the mesh and grid, data packets are sent after 1 second in the simulations. All the results presented in this paper are an average of 10 different simulation trials with a 95% confidence interval.

Two metrics are used in our comparison: One Success Delivery Ratio and Packet Overhead per One Success. If the source sends a data packet and at least one of the nodes in the geocast region receives the data packet, we call the entire scenario "One Success" (the results for "All Success", which calculates the delivery ratio for all nodes in the geocast region receiving the data packet, were similar to the results for "One Success"). The Packet Overhead is a sum of the number of transmitted packets (data and control) by all nodes in the simulation respectively. Due to space constraints, we do not present results for Byte Overhead per One Success. We note that these results follow the same trends as the Packet Overhead results. For specific results, see [11].

5 Simulation results

To provide a side-by-side comparison of the geocast protocols, we focus on four studies. These studies compare the protocols over a range of network conditions including node densities, node mobility and traffic rates. Each study is outlined in a subsection below.

5.1 Study 1 - Algorithm Efficiency

To evaluate the core algorithms of the different protocols, Study 1 compared their performance in a static network using a Null MAC. We varied the number of nodes in the network area from 30 to 120 and fixed the source at (50, 100) to decrease the variability in the distance between the source and geocast region. A geocast packet origination rate of 40 packets per second was used, although the use of a Null MAC renders the origination rate irrelevant.

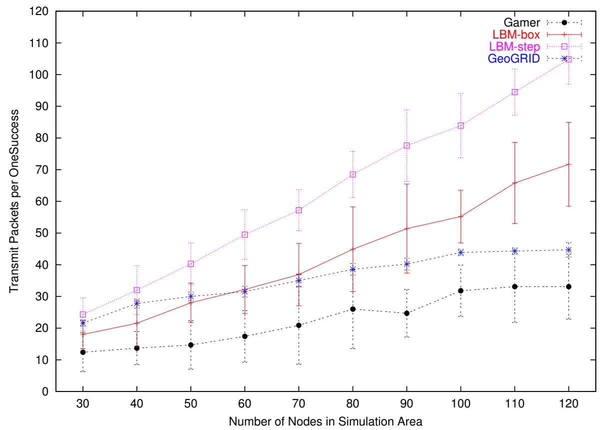

Figure 4: Study 1 (NULL MAC and static networks): Packet Overhead per One Success versus Number of Network Nodes.

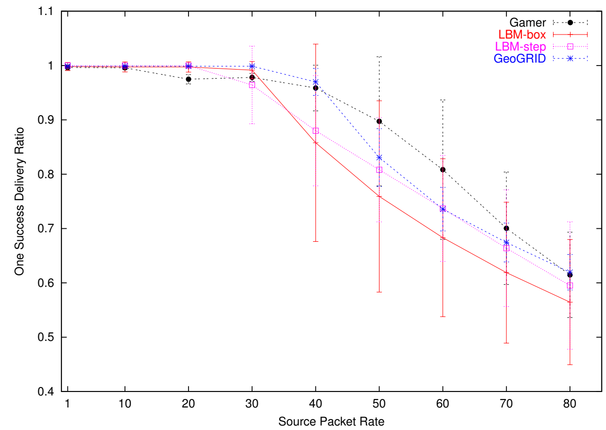

Figure 5: Study 2 (802.11 MAC and static networks): One Success Delivery Ratio versus Packet Origination Rate.

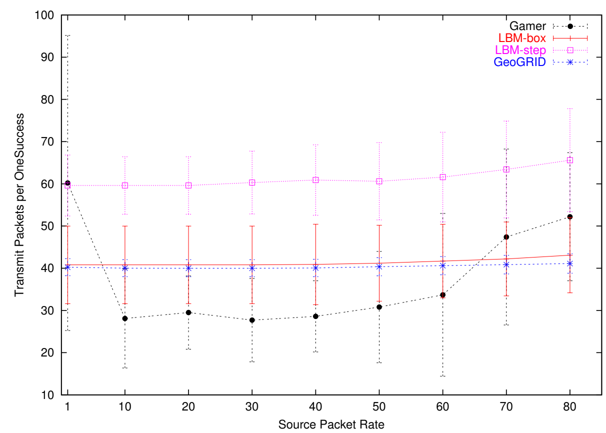

Figure 6: Study 2 (802.11 MAC and static networks): Packet Overhead per One Success versus Packet Origination Rate.

Since the network was static and no collisions were allowed to occur, network conditions that prevented packets from being received rarely occurred. Therefore, One Success Delivery Ratio for Study 1 was almost always 100%. Thus we've omitted the graph of these results.

Due to idiosyncrasies of GeoGRID and LBM-box, there were some simulations where delivery rate was exactly zero (e.g., a network partition among the gateways). Because Packets per One Success is invalid if the delivery ratio is zero, we do not include these simulations in the Packet per One Success results for Study 1. Figure 4 shows GAMER is the cheapest in terms of packet overhead, followed by GeoGRID, LBM-box, and LBM-step. Control packets (if they exist) are sent approximately every second while realistic applications demand that data packets be sent tens and hundreds of times per second. Therefore, those protocols that are willing to use control packets to reduce data packets are likely to send fewer packets. GeoGRID has a lower packet overhead than LBM-box when 80 or more nodes are present in the network. 80 nodes is the network density where grids start having more than one node in them. That is, 80 nodes is the network density where GeoGRID begins having a savings in packet transmissions due to the gateways. LBM-step is worse than LBM-box because in most cases it results in a larger forwarding zone.

5.2 Study 2 - Congested Networks

To quantify the effect of congestion on each of the protocols, Study 2 used the 802.11 MAC in a static network. In this study, the payload portion of each packet was set at 64 bytes and the rate was varied from 1 packet per second to 80 packets per second. The number of network nodes was set at 80, roughly the median value from Study 1. A static network was used for this study to ensure that the effects of mobility would not interfere with the effects of congestion. As in Study 1, the source is fixed at (50, 100).

Figure 5 shows that for packet origination rates of 30 pkts/s or below, the One Success Delivery Ratio is 100%. The performance of LBM-box and LBM-step deteriorate the soonest, because these two protocols have the most flooding and therefore collision-prone results. GeoGRID is slightly better, and interestingly has an average One Success Delivery Ratio of almost exactly 0.05 higher than LBM-box for most of the data points. These simulations are networks with 80 nodes, which is where GeoGRID begins to be less congested than LBM-box (see Section 5.1). Overall, when the confidence intervals are considered, the four protocols have approximately the same delivery ratio.

In Figure 6, most of the protocols appear to require a number of transmissions per delivered packet proportional to the packet origination rate. The exception is GAMER, which has periodic control overhead that does not depend upon the packet source rate, giving GAMER a larger control overhead for low packet origination rates. For highly congested networks, GAMER's control packets rise signif-

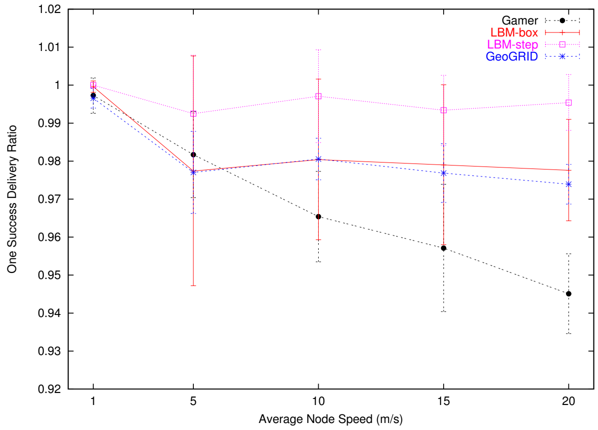

Figure 7: Study 3 (NULL MAC and mobile networks): One Success Delivery Ratio versus Average Node Speed.

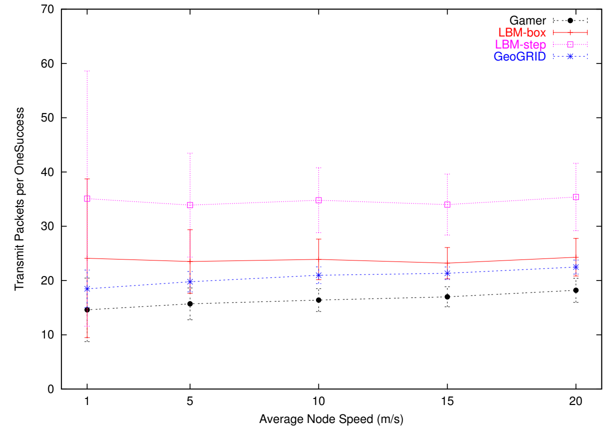

Figure 8: Study 3 (NULL MAC and mobile networks): Packet Overhead per One Success versus Average Node Speed.

icantly due to the difficulty in making a successful mesh query in a busy network.

5.3 Study 3 - Mobile Networks

This study focuses on the ability of each protocol to react effectively to node mobility in the network. A Null MAC is used in this study to ensure no effects from congestion. The packet source rate was set at 40 packets per second. As in Study 2, the number of network nodes was set at 80. The range of mean speeds is varied from 1 to 20 meters per second in our simulations.

Figure 7 shows that most of the protocols perform well (above 97% delivery ratio) in a mobile situation. The performance of the GAMER protocol deteriorates the most as speed increases. GAMER requires that a mesh be maintained in order for packets to be successfully transmitted, which can be broken due to mobility. LBM and GeoGRID are not as sensitive to mobility because they are not concerned with which nodes happen to be in the forwarding region at any given time. LBM has no state and GeoGRID's state only requires repair when gateways move out of the grid, making both protocols more resilient to topology changes than GAMER. LBM-step has the greatest One Success Delivery Ratio because it has the largest forwarding zone.

As shown in Figure 8, all the protocols are basically insensitive to mobility with respect to Packet Overhead per One Success. GAMER transmits the fewest packets for all speeds. The overhead of GeoGRID and GAMER both climb slightly due to the extra control overhead required to maintain their state in an unstable network, while both varieties of LBM are statistically unaffected by mobility.

5.4 Study 4 - Combined Networks

In the previous three studies, we only varied one parameter. To complete our evaluation of LBM, GAMER and GeoGRID, we chose to aggregate the simulation parameters into five trials to give an overview of performance at combined conditions. The five trials are designed so that Trial 1 takes a combination of the least severe conditions and Trial 5 takes a combination of the most severe conditions. The specific parameters are shown in Table 1.

Trial	1	2	3	4	5
Number of Nodes	60	70	80	90	100
Avg. Speed (m/sec)	1	5	10	15	20
Pkt. Src. Rate (pkts/sec)	20	30	40	50	60

Table 1: Study 4 Trial Simulation Parameters.

In Figure 9, the One Success Delivery Ratio for all the protocols is almost perfect (i.e., above 95% delivery ratio) for Trials 1-3. However, as the network becomes more severe, the delivery ratio of GAMER and LBM drop due to mobility and transmission rate respectively. Since GeoGRID is insensitive to these factors above node densities of 80, it emerges as the clear winner for extremely severe network conditions.

Figure 10 shows that packet overhead is essentially a repetition of the results in the previous three studies. That is, GAMER uses the least number of packets per delivered packet.

6 Conclusions and Future Work

In order to obtain a comprehensive comparison of existing geocast routing protocols, we classified the protocols into three categories. We chose to evaluate LBM from the flooding based protocols, GAMER from the routing based protocols, and GeoGRID from the cluster-based protocols. We performed four studies on each of the protocols to determine their relative strengths and weaknesses: node density, node mobility, node speed, and a combination study of five trials.

We arrive at three conclusions: First, LBM's chief merit is its simplicity. LBM never beats the performance of Ge-

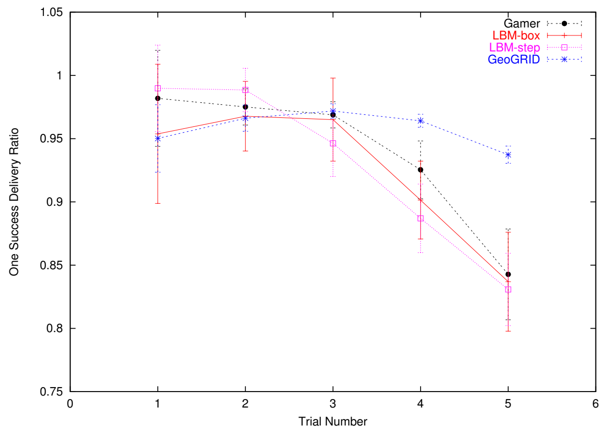

Figure 9: Study 4 (802.11 MAC and Combined Networks): One Success Delivery Ratio versus Severity of Network Environment Increases.

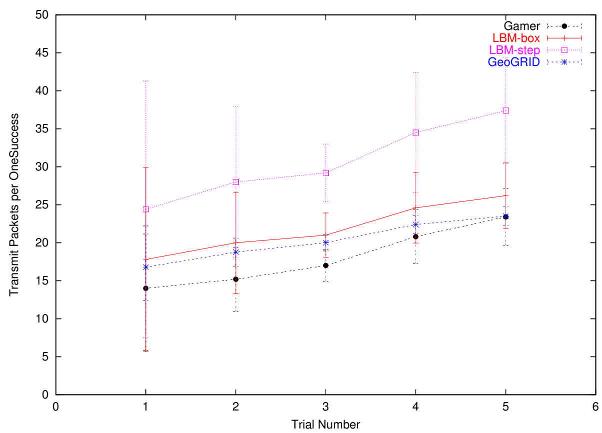

Figure 10: Study 4 (802.11 MAC and Combined Networks): Packet Overhead per One Success versus Severity of Network Environment Increases.

oGRID or GAMER, but does perform equivalently in some cases. LBM-box is generally preferable to LBM-step because of the large packet overhead in LBM-step. Second, GAMER consistently either ties or has the absolute lowest value for packet overhead. In networks where packet overhead is the only concern, GAMER is preferable. Finally, GeoGRID is the most robust, especially in dense networks. GeoGRID does, however, suffer connectivity issues in sparse networks.

In the future, we plan to investigate whether flooding among specific nodes used in LBM and GeoGRID (whether using gateways or an efficient flooding algorithm) can be improved to produce networks with high connectivity and low control overhead. Also, since geocasting algorithms can involve anycasting to the geocast region (whether this results in a route-based geocasting algorithm or a flood-based geocasting algorithm), we plan to implement geocast versions of unicast protocols such as LAR to evaluate their performance. Finally, we plan to add an acknowledgment mechanism to geocast protocols to make transmissions reliable by allowing dropped messages to be resent.

References

[1] J. Boleng, T. Camp, and V. Tolety. Mesh-based geocast routing protocols in an ad hoc network. In *Proceedings of IPDPS*, pages 184–193, April 2001.

[2] J. Broch, D. Maltz, D. Johnson, Y. Hu, and J. Jetcheva. Multi-hop wireless ad hoc network routing protocols. In *Proceedings of MOBICOM*, pages 85–97, 1998.

[3] T. Camp and Y. Liu. An adaptive mesh-based protocol for geocast routing. *Journal of Parallel and Distributed Computing: Special Issue on Routing in Mobile and Wireless Ad Hoc Networks*, 62(2):196–213, 2003.

[4] C.-Y. Chang, C.-T. Chang, and S.-C. Tu. Obstacle-free geocasting protocols for single/multi-destination short message services in ad hoc networks. *Wireless Networks*, 9(2):143–155, 2003.

[5] Y. Ko and N. H. Vaidya. GeoTORA: A protocol for geocasting in mobile ad hoc networks. In *Proceedings of ICNP*, pages 240–250, November 2000.

[6] Y. Ko and N.H. Vaidya. Geocasting in mobile ad hoc networks: Location-based multicast algorithms. In *Proceedings of WMCSA*, pages 101–110, 1999.

[7] W.-H. Liao, Y.-C. Tseng, K.-L. Lo, and J.-P. Sheu. GeoGRID: A geocasting protocol for mobile ad hoc networks based on GRID. *Journal of Internet Technology*, 1(2):23–32, 2000.

[8] W. Navidi, T. Camp, and N. Bauer. Improving the accuracy of random waypoint simulations through steady-state initialization. In *Proceedings of the 15th International Conference on Modeling and Simulation (MS 2004)*, pages 319–326, 2004.

[9] The VINT Project. The network simulator - ns-2. http://www.isi.edu/nsnam/ns/. Page accessed on Feb. 20th, 2004.

[10] I. Stojmenovic. Voronoi diagram and convex hull based geocasting and routing in wireless networks. Technical Report, University of Ottawa, TR-99-11, December 1999.

[11] P. Yao, E. Krohne, and T. Camp. Performance comparison of geocast routing protocols for a manet. Technical report, Department of Math. and Computer Sciences, Colorado School of Mines, May 2004.

[12] J. Yoon, M. Liu, and B. Noble. Random waypoint considered harmful. In *Proceedings of INFOCOM*, pages 1312–1321, 2003.