Evaluation of Three Geocasting Protocols for a MANET [*]

Peiling Yao
pyao@mines.edu
Ed Krohne
ekrohne@mines.edu
Tracy Camp
tcamp@mines.edu
Dept. of Math. and Computer Sciences
Colorado School of Mines
Golden, CO, 80401

Abstract

A mobile ad hoc network (MANET) is a network consisting of a set of mobile nodes capable of communicating with each other without the assistance of base stations. The goal of a geocasting protocol is to deliver data packets to a group of nodes that are located within a specified geographical area, i.e., the geocast region. In this paper, we evaluate the performance of three geocast routing protocols for a MANET via simulation: Location-Based Multicast, GeoGRID, and Geocast Adaptive Mesh Environment for Routing.

1 Introduction

A mobile ad hoc network (MANET) is a set of wireless mobile nodes (MNs) that cooperatively form a network without specific user administration or configuration. Numerous scenarios do not have an available network infrastructure and could benefit from the creation of an ad hoc network: rescue/emergency operations, law enforcement activities, tactical/military missions, and educational settings. For these reasons, ad hoc networks have been a major focus of research in the last several years.

There are many challenges in the creation of an ad hoc network: routing challenges (i.e., how to route information to a mobile node that is, perhaps, moving rapidly), wireless medium challenges (e.g., lower bandwidths, higher error rates, more frequent disconnections, and less security than fiber lines), and portability challenges (e.g., lower power than desktop computers). This paper concerns routing. Each node in a MANET, whether it be a laptop, autonomous agent, or sensor, is in charge of routing information between its neighbors, thus maintaining connectivity of the network.

The goal of a geocasting protocol is to deliver a packet to a set of nodes within a specified geographical area, i.e., the geocast region. For example, during a rescue/emergency operation, consider the benefits of delivering a message, which states immediate help is needed at 950 Illinois Street, to all rescue personnel in the 900 block of Illinois Street. In geocasting, the nodes eligible to receive packets are implicitly specified by a physical region; membership in a geocast group changes whenever an MN moves in or out of the geocast region. Since geographical areas are defined, we require knowledge of geographical locations. Thus, we assume the existence of some location information system, such as the Global Positioning System (GPS), to obtain this information.

In [5], five existing geocast protocols are classified into two categories: data-transmission oriented protocols and routing-creation oriented protocols. The difference between these two categories is how a protocol transmits information from a source to the nodes in the geocast region. Data-transmission oriented protocols use flooding or a variant of flooding to forward geocast packets from the source to the geocast region. Routing-creation oriented protocols create routes from the source to the geocast region via control packets. In this paper, we evaluate the performance (via simulation) of two data-transmission oriented protocols and one routing-creation oriented protocol.

2 Geocast Protocols Evaluated

In this section, we discuss two data-transmission oriented protocols (i.e., Location-Based Multicast [7, 8] and GeoGRID [10]) and one routing-creation oriented protocol (i.e., Geocast Adaptive Mesh Environment for Routing [4]). As mentioned, these two categories for geocast protocols were first defined in [5].

2.1 Location-Based Multicast (LBM)

2.1.1 Protocol Description

The Location-Based Multicast (LBM) protocol [7, 8] is a restricted flooding approach to geocasting. LBM is derived from a previous unicast protocol by the same authors, i.e.,

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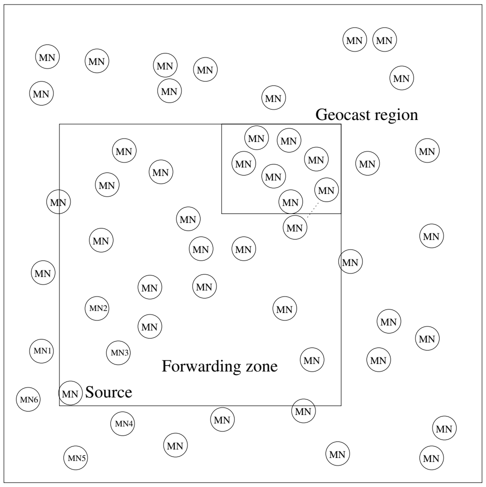

Figure 1: LBM Scheme 1 (or LBM-box).

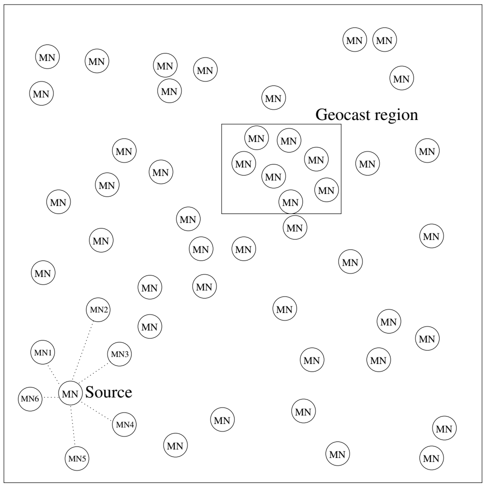

Figure 2: LBM Scheme 2 (or LBM-step).

the Location-Aided Routing (LAR) protocol [6]. LBM is essentially identical to flooding data packets, with the modification that a node determines whether to forward a geocast packet via one of two schemes.

LBM Scheme 1: When a node receives a geocast packet, it will forward the packet to its neighbors if it is within a *forwarding zone*; otherwise, it will discard the packet. Figure 1 illustrates a BOX forwarding zone example. A BOX forwarding zone is the smallest rectangle that covers both the source node and the geocast region. The authors of LBM mention that additional control on the size of the forwarding zone is possible using a parameter $\delta > 0$ [7, 8]. When $\delta > 0$, the forwarding zone is extended such that each side of the forwarding zone increases by 2δ. We implement a BOX forwarding zone for LBM. Thus, we refer to LBM Scheme 1 as LBM-box.

LBM Scheme 2: When a node *A* receives a geocast packet from node *B*, node *A* will forward the packet if node *A* is "at least δ closer" to the center of the geocast region than node *B* [7, 8]. Figure 2 illustrates an example of LBM Scheme 2. In this figure, mobile nodes 1-4 are closer to the center of the geocast region than the source. Thus, if $\delta = 0$, MN1, MN2, MN3, and MN4 will forward the received geocast packet. MN5 and MN6 will discard the geocast packet since these two nodes are not closer to the center of the geocast region than the source. We refer to LBM Scheme 2 as LBM-step. We note that the example in Figure 2 for LBM-step shows two more nodes forwarding each geocast packet sent by the source than the similar example in Figure 1 for LBM-box.

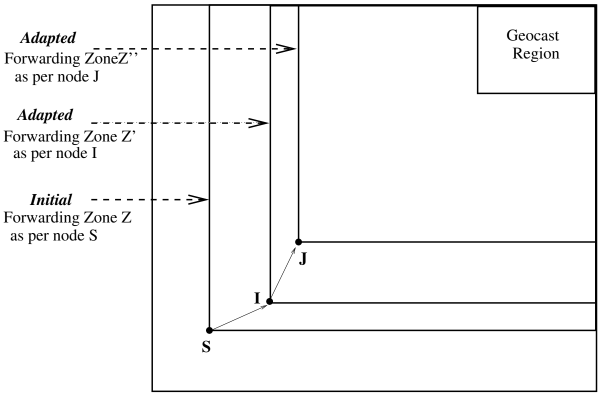

Figure 3: Adaptation of the LBM-box scheme.

2.1.2 Protocol Implementation

In our implementation of LBM, we set δ to 30 meters for LBM-box and δ to 0 meters for LBM-step. We also implement one of the LBM-box improvements described in [8]. Specifically, we implement an adaptive forwarding zone for LBM-box. In this improvement, the forwarding zone adapts to be the smallest rectangle that covers both the node that most recently transmitted the geocast packet and the geocast region. For example, in Figure 3 (which is similar to a figure in [8]), node I receives the packet from source S and forwards the packet to its neighbors because node I is within the forwarding zone Z. Only nodes in the forwarding zone Z' (e.g., node J) will forward the packet received from node I.

2.2 GeoGRID

2.2.1 Protocol Description

GeoGRID [10] is derived from a previous unicast protocol by the same authors, i.e., GRID [9]. Both GRID and GeoGRID partition the geographic area of the MANET into 2D logical grids. Each grid is a square of size d×d. The forwarding zone is defined by the location of the source

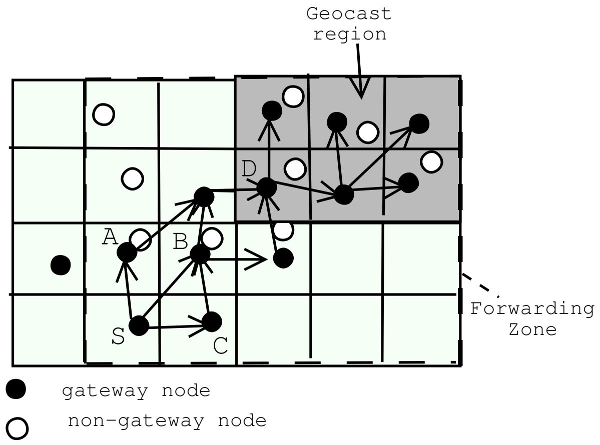

Figure 4: An example for flooding-based GeoGRID.

and the geocast region, similar to the forwarding zone defined in the non-adaptive version of LBM-box. Within each grid, a special node called a *gateway* is elected. The main difference between LBM and GeoGRID is that only gateway nodes in a forwarding zone have the responsibility to forward geocast packets. There are two versions of GeoGRID: flooding-based GeoGRID and ticket-based GeoGRID [10].

In *flooding-based GeoGRID*, only gateways in every grid within the forwarding zone rebroadcast the received geocast packets (see Figure 4, which is similar to a figure in [10], for an example). This is also true with *ticket-based GeoGRID*, except that not all the gateways in the forwarding zone will forward each geocast packet in ticket-based GeoGRID. Instead, in ticket-based GeoGRID, the source evenly distributes $(m+n)$ tickets (for a geocast region of $(m \times n)$ grids) to the neighboring gateway nodes in the forwarding zone that are closer to the geocast region than the source. A gateway node that receives X tickets follows the same procedure as the one defined for the source.

If a node is unaware of a gateway for its grid, it offers to become the gateway by sending a BID packet to its neighbors. A node that receives a BID packet and is closer to the center of the grid will transmit its own BID packet. The node that transmits the last BID packet in a grid becomes the gateway, if a gateway did not previously exist. Each gateway transmits GATE packets within the gateway's grid periodically and whenever a BID packet is received. GATE packets are considered trump, regardless of the locations of the gateway and the bidder. An elected gateway remains the gateway for the grid until it moves out of the grid.

2.2.2 Protocol Implementation

In our implementation of GeoGRID, we set the width of each grid to be $\frac{T_{range}*\sqrt{2}}{3}$ meters, where T_{range} is the simulation's transmission range. In addition, each gateway evaluates whether it has left the grid every 300ms. If the gateway has left its grid, the gateway transmits a RETIRE packet within the grid. This RETIRE packet initiates a new gateway election for the grid. During an election, a gateway is considered elected if 2 ms passes without the transmission of another BID packet. Finally, we found the performance of GeoGRID is higher if we do not transmit GATE packets periodically. Thus, the interval for a gateway to transmit a GATE packet is set higher than the simulation time.

2.3 Geocast Adaptive Mesh Environment for Routing (GAMER)

2.3.1 Protocol Description

The Geocast Adaptive Mesh Environment for Routing (GAMER) protocol attempts to create *redundant* routes from a source to a geocast region. A single route from a source to a geocast region is fragile in a mobile environment, especially when the mobile nodes are moving quickly. Thus, the authors of GAMER [4] propose a mesh-based geocast protocol that provides redundant paths between the source and the geocast region.

A source wishing to transmit packets to a geocast region will first flood JOIN-DEMAND packets in a forwarding zone. A JOIN-DEMAND packet is forwarded in the forwarding zone until it reaches a node in the geocast region. This node unicasts a JOIN-TABLE packet back to the source following the reverse route taken by the JOIN-DEMAND packet. When the source receives its first JOIN-TABLE packet, it can begin sending geocast packets via the mesh to the geocast region.

GAMER adapts to the current network environment by dynamically changing the size of the forwarding zone, which dynamically changes the density of the mesh in real-time [4]. As a result, when nodes are highly mobile, a dense mesh is created; when nodes are moving slowly, a sparse mesh is created. The CONE, CORRIDOR and FLOOD forwarding zones are the three candidates that a source node can choose in GAMER. These three forwarding zones are illustrated in Figure 5 (a figure similar to a figure in [4]).

The authors of GAMER propose two versions of GAMER: passive GAMER and active GAMER. In passive GAMER, the JOIN-DEMAND packets are transmitted at a fixed frequency. In other words, a JOIN-DEMAND packet is sent at every JOIN-DEMAND packet interval regardless of whether a JOIN-TABLE packet is received. In Active GAMER, the JOIN-DEMAND packets are transmitted at the same fixed frequency *and* at a higher rate if a JOIN-TABLE packet is not returned within a given timeout period (i.e., SWITCH-TIMER).

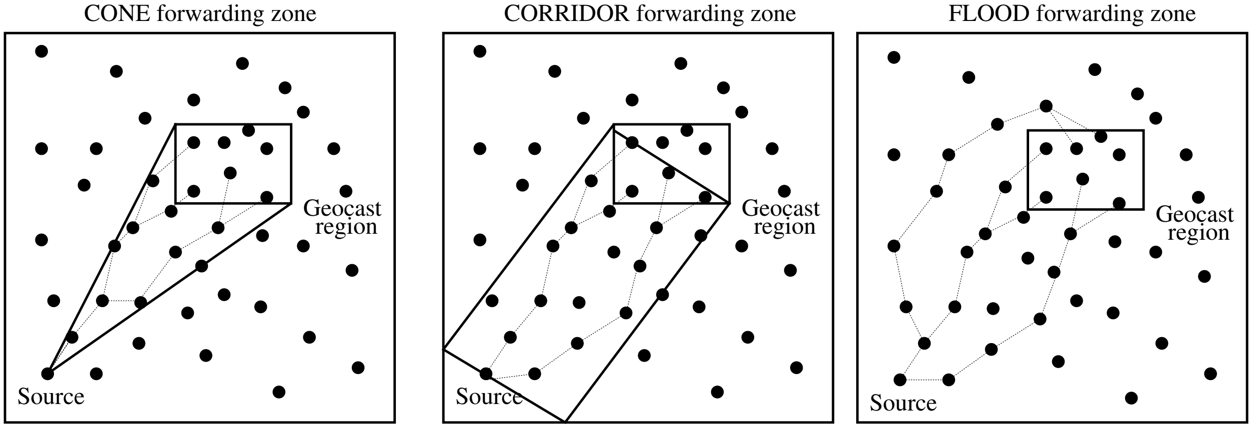

Figure 5: The GAMER mesh created in the CONE, CORRIDOR and FLOOD forwarding zones.

Simulator	NS-2
Simulation area (w x h)	300m x 600m
Geocast region	150m x 150m
Number of MNs (n)	50
Transmission range (r)	100 m
Bandwidth	2 Mbps
Mobility model	random waypoint
Mobility speed	0, 5, 10, 15, 20m/s ±10%
Pause time	10s ±10%
Simulation time	1000 s
CBR sources	1
Packet rate	40 packets/s
Data payload	64 bytes

Table 1: Simulation parameters

2.3.2 Protocol Implementation

Since active GAMER is more active in increasing the size of its forwarding zone than passive GAMER [4], we simulate Active GAMER for our performance evaluation. There are three key parameters in the active GAMER protocol: the JOIN-DEMAND packet interval, the SWITCH-TIMER period, and the mesh-member timeout. As mentioned, the JOIN-DEMAND packet interval is the interval in which the source floods JOIN-DEMAND packets. In our implementation of GAMER, we set this interval to be 0.5 seconds. The SWITCH-TIMER period is the timer for the size of the forwarding zone to adapt. In our implementation of GAMER, we set this timer to be 0.1 seconds. Finally, the mesh-member timeout defines the lifetime of a given mesh member. In our implementation of GAMER, we set this timeout to be 2 seconds.

3 Performance Evaluation

3.1 Simulation Environment

We implement the LBM-box, LBM-step, GeoGRID, and GAMER geocast protocols in the network simulator NS-2 [12]. The simulation area is a 300 x 600 meter rectangle, and the geocast region is a 150 x 150 meter square located in the upper right corner of the simulation area. In each 1000 seconds simulation period, the single Constant Bit Rate (CBR) source generates 40 geocast data packets per second and the size of each geocast data packet is 64 bytes.

We simulate 50 mobile nodes (MNs) moving in the simulation area at a variety of speeds. We place one static node in the center of the geocast region, i.e., location (225, 525), in order to ensure that at least one node exists in the geocast region to receive the geocast packets transmitted. Node mobility uses the random waypoint mobility model [2]. In this model, each MN randomly selects a destination and then moves toward that destination at a given speed. Once the destination is reached, the MN pauses for a given pause time. It then selects another destination and repeats the above behavior. 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) [11]. Thus, we avoid the initialization problem of the random waypoint mobility model which is discussed in [3] and [13].

In our simulation, the mean mobility speeds are 0, 5, 10, 15, and 20 m/s ± 10%. The mean pause time is 10 seconds ± 10%. Each MN has a uniform transmission range of 100 meters. We assume the bandwidth available for each MN is 2 megabit per second (Mbps). Table 1 summarizes our simulation parameters.

Derived parameters are calculated from the above simulation parameters [1]. Table 2 lists these derived parame-

Node density	$\frac{n}{w*h}$	1 per 3,600 m^2
Coverage area	$\pi * r^2$	31,416 m^2
Trans. footprint	$\frac{\pi*r^2}{w*h}$	17.45%
Max. path length	$\sqrt{w^2+h^2}$	671 m
Net. diameter	$\frac{\sqrt{w^2+h^2}}{r}$	6.71 hops
Avg. # neighbors	$\pi * r^2 * \frac{n}{w*h} - 1$	7.7

Table 2: Derived simulation parameters

ters and the equations used to calculate them. The number of MNs in our simulation is represented by n; w and h represent the width and height of the simulation area respectively and r represents the transmission range of each MN.

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 for the mesh to build and the grids to elect gateways, data packets are sent after 1 second of simulation time. All the results presented in this paper are an average of 10 different simulation trials with a 95% confidence interval.

Three metrics are used in our comparison: One Success Delivery Ratio, Packet Overhead per One Success and Byte Overhead per One Success. If the source sends a data packet for all the nodes in the geocast region, and one of the nodes in the geocast region receives the data packet, we call the entire scenario “One Success”. If all the nodes in the geocast region (at the time the data packet is sent) receive the data packet, we call the scenario “All Success”. In all our simulation results, the All Success Delivery Ratio is only a little lower than the One Success Delivery Ratio. Thus, we only show One Success Delivery Ratio results in this paper. The Packet Overhead is the sum of the number of transmitted packets (data and control) for all the nodes in the simulation. The Byte Overhead is the sum of the bytes (data and control) transmitted for all the nodes.

3.2 Simulation Results

Figure 6 illustrates One Success Delivery Ratio of the four protocols we evaluate. For static networks, LBM-box, LBM-step and GAMER have a very high delivery ratio while GeoGRID only gets 90%. At speeds greater than 5 m/s, all protocols see approximately a 5% drop. The decrease in delivery ratio is likely due to partitions in the network that develop after the nodes begin to move.

The delivery ratio of GeoGRID is less than the delivery ratio of other protocols due to GeoGRID’s sensitivity to sparse networks. In our simulations, the steady-state random waypoint mobility model results in approximately 12.5% of all grids having two or more nodes. Since only one node in a grid is allowed to transmit, the average effective number of nodes in the network able to transmit is only 36.4 (or only 73% of the nodes in the network).

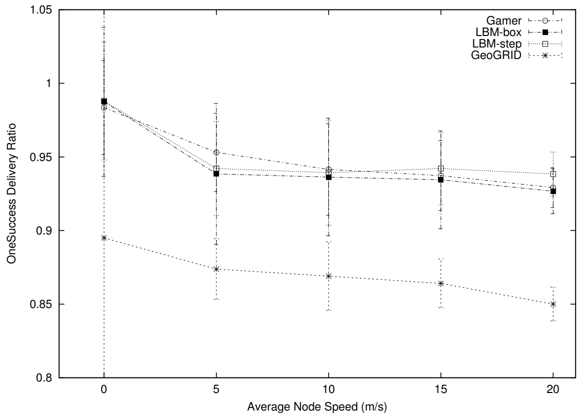

Figure 6: One Success Delivery Ratio versus Average Node Speed.

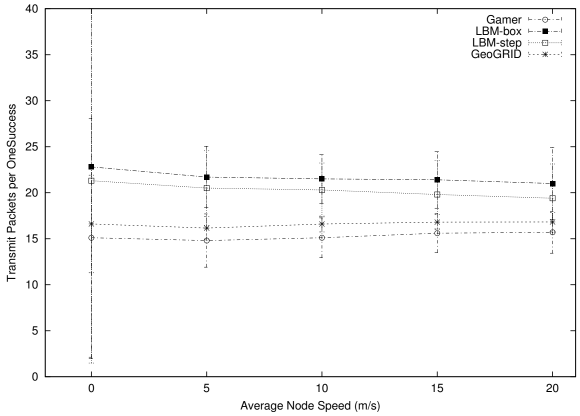

Figure 7: Packet Overhead per One Success versus Average Node Speed.

Figures 7 and 8 show that GeoGRID and GAMER offer less overhead than both of the LBM protocols. While the amount of overhead in LBM-box and LBM-step is approximately the same, GeoGRID has the lowest byte overhead and GAMER has the lowest packet overhead. LBM-box and LBM-step have the largest area in which they flood, thus the higher overhead of these two protocols is expected. GeoGRID effectively reduces its forwarding zone, not by decreasing its size but by allowing only 73% of all nodes to transmit. GAMER has lower overhead than the LBM protocols because GAMER, instead of flooding data, sends data through routes.

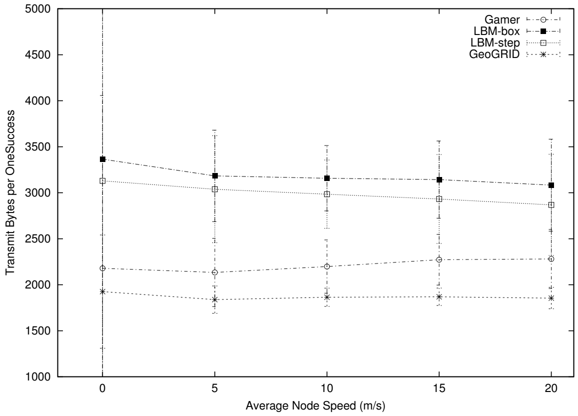

Figure 8: Byte Overhead per One Success versus Average Node Speed.

4 Conclusions and Future Work

Of the four geocast protocols evaluated, GAMER offers the best performance overall. While LBM-box and LBM-step have equivalent delivery ratio as GAMER, the overhead of GAMER is much lower that both LBM protocols. The chief merit of LBM is its simplicity to implement. GeoGRID fares poorly in delivery ratio, but offers the lower byte overhead. LBM-box and LBM-step gave similar results in all cases. Setting δ equal to 30 meters in LBM-box creates a forwarding zone that is approximately the same size as the zone in LBM-step.

While GeoGRID proved poorly in our performance evaluation, we are convinced that it will out-perform the other protocols if denser networks are used. Specifically, if the network density was large enough to ensure at least one node in each grid, GeoGRID would offer a much higher delivery ratio with a very small increase in overhead. We also note that only one source (transmitting 40 packets per second) existed in our simulations. We suspect GeoGRID would out-perform the other protocols if more congestion was added to the network. To discover the effects of congestion and node density on these four protocols, we plan to perform further studies that evaluate the effects of node density, packet transmission rate, and node mobility.

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