GeoGRID: A Geocasting Protocol for Mobile Ad Hoc Networks Based on GRID*

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Abstract

A *mobile ad hoc network (MANET)* is one consisting of a set of mobile hosts capable of communicating with each other without the assistance of base stations. One prospective direction to use such networks is to adopt positioning devices (such as global positioning system, GPS) to provide *location-aware services*. This paper discusses an attractive service called *geocasting*, or *location-based broadcasting*, whose goal is to send a message targeted at mobile hosts resident within a specified geographical region (such as a building, a street, a commercial area, etc.). In this paper, we propose a new routing protocol for geocasting called *GeoGRID*, which is based on our earlier unicast protocol GRID [14]. The protocol is featured by utilizing location information, confining the flooding zone, and electing a special host in each grid area responsible of forwarding the geocast messages. Simulation results show that our GeoGRID protocol can reduce network traffic and achieve higher data arrival rate.

Keywords: geocast, Global Positioning System (GPS), location-aware applications, mobile ad hoc network (MANET), mobile computing, wireless communication.

1 Introduction

The advancement in wireless communication and economical, portable computing devices have made *mobile computing* possible [7]. One research issue that has attracted a lot of attention recently is the design of *mobile ad hoc network (MANET)*. A MANET is one consisting of a set of mobile hosts which can communicate with one another and roam around at their will. No base stations are supported in such an environment. Due to considerations such as radio power limitation, power consumption, and channel utilization, a mobile host may not be able

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to communicate directly with other hosts in a *single-hop* fashion. In this case, a *multi-hop* scenario occurs, where the packets sent by the source host are relayed by several intermediate hosts before reaching the destination host. Applications of MANETs occur in situations like battlefields or major disaster areas, where networks need to be deployed immediately but base stations or fixed network infrastructures are not available. A working group called "manet" has been formed by the Internet Engineering Task Force (IETF) to study the related issues and stimulate research in MANET [1].

Since a MANET is likely to operate in a physical area, it is very natural to apply location information of mobile hosts on such an environment. We call this property *location awareness*, meaning that a mobile host may know its own physical location, and the physical locations of some other mobiles (perhaps through communication). One way for a mobile host to know its current location is through a GPS (global positioning system) receiver connected to the host [6, 10]. It is worth noting that GPS-related applications are quickly gaining popularity. As observed in [9, 13], location-aware or context-aware applications will be an important domain in mobile computing. Examples include navigation systems, telematic systems to facilitate communication with moving vehicles, geocasting, and tour guide systems. The GPS receiver can determine its position, velocity, and precise timing from the information received from the satellites. The accuracy of the GPS system ranges from tens to hundreds meters. To improve its accuracy, assistance from ground stations can be applied. Such systems, called *differential GPS (DGPS)*, can reduce the error to less than a few meters [13]. Availability of location information may have a broad impact on different protocol layers in a MANET. In [11, 12, 14], location-aware unicast routing on MANET is discussed. They try to use the location information of the destination node to reduce the overhead of route discovery. In [16], location information is used to assist broadcasting in a MANET.

This paper investigates the *geocasting problem* in a MANET. A geocast is to send a message from a source host to all mobile hosts resident in a given geographical region. Although the goal is to send a message to a group of hosts, this problem distinguishes itself from the traditional multicast problem in that the receiving hosts are specified by *locations*, instead of particular *multicast addresses*. In geocasting, the hosts eligible of receiving the messages are implicitly specified by a physical region. Further, the receiving members may change dynamically by time due to host mobility. Geocasting may have many interesting applications. It can be used to perform regional broadcast to deliver geographic-related commercials, advertisements, etc. Sending emergency messages to a specific area (such as a building, an assembly field ground, a gymnasium, a bus/train station, etc.) is another example. One direct solution to geocasting is to apply existing multicasting protocols for MANET (such as [2, 4, 5, 17]). However, since MANET is typically characterized by high host mobility, the movement of hosts may cause frequent reconfigurations of the multicast tree (and thus high tree maintenance costs). Another approach is by flooding. However, as pointed out in [16], flooding in a MANET may cause a lot of contention, collision, and redundancy. To reduce to flooding cost, it is proposed in [12] to utilize the current location of the source host and the target geocasting region to limit the range of flooding. In this paper, we propose a new approach called GeoGRID for geocasting in a MANET. This protocol is an extension of our earlier protocol GRID [14], which is for unicast. In GeoGRID, we treat the geographic area as a number of logical grids, each as a square. In each grid, one mobile host (if any) will be elected as the leader of the grid. Geocasting is then performed in a grid-by-grid manner through grid leaders [14]. Through simulations, we justify that our GeoGRID protocol not only reduces the network traffic, but also increases the arrival rate of geocast messages.

The rest of the paper is organized as follows. Section 2 presents some background and motivation of this work. Our protocol is developed in Section 3. Experimental results are shown in Section 4. Section 5 concludes the paper.

2 Background and Motivation

2.1 Review of Geocasting Protocols

The geocasting problem is first proposed by Navas and Imielinski [15]. In that work, which focuses on the Internet, multicast group members are defined as all nodes within a certain region. To support location-dependent services such as geographic advertising, three approaches are suggested: (i) geo-routing with location-aware routers, (ii) geo-multicasting modified from IP multicast, and (iii) application-layer solution extending from Domain Name Service (DNS).

The first geocasting work on MANET is [12]. Their scheme is based on confined flooding. Location information of the source host and the destination zone is used define the flooding area. Specifically, the *forwarding zone* is defined to be the smallest rectangle that includes the location of the sender and the destination region, such that the rectangle is parallel to the X (horizontal) and Y (vertical) axes. For example, in Fig. 1, the geocast region is the rectangle bounded by O, P, B, and Q. If S is the source, the forwarding zone will be the rectangle bounded by S, A, B, and C. Node S, when initiating a geocast, will include the coordinates of the forwarding zone. A node within the forwarding zone (such as node I in the figure), on receiving the geocast message, will rebroadcast the message. However, a node not within the forwarding zone (such as node J), will discard the message.

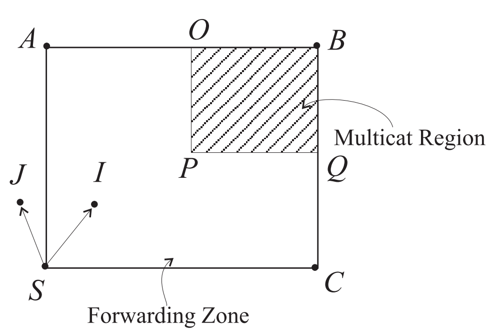

Fig. 1: Forwarding zone in the geocast protocol by [12].

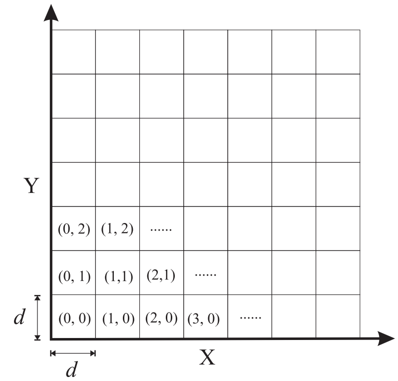

Fig. 2: Logical grids to partition a physical area.

2.2 Observations and Motivations

In [12], although using forwarding zones can avoid network-wide flooding, there may still exist a lot of unnecessary flooding packets within a forwarding zone. It is worth pointing out that flooding is an unwise, and sometimes very costly, operation. As demonstrated in [16], flooding may cause a *storming* effect with serious redundancy, contention, and collision.

First, because radio propagation is omni-directional, a physical location may be covered by several retransmissions of the geocast message from its neighbors. Except the first message, the other retransmissions are redundant to this host. Second, heavy contention could exist because rebroadcasting hosts are probably close to each other. Third, collisions are more likely to occur because the RTS/CTS dialogue is inapplicable and the timing of rebroadcasts is highly correlated. Collectively, these problems are called the *broadcast storm problem* [16].

It is worth noting that existing multicast protocols [2, 4, 5, 17] based on multicast trees (which connect the receiving hosts) may not work well either. The reason is the high uncertainty of host mobility in a MANET. So a tree-based solution is prohibitive.

3 The GeoGRID Protocol

3.1 GRID Construction

Our protocol is called *GeoGRID*. The geographic area of the MANET is partitioned into 2D logical grids as illustrated in Fig. 2. Each grid is a square of size $d \times d$. Grids are numbered (x, y) following the conventional xy-coordinate. Each host still has a unique ID (such as IP address). To be location-aware, each mobile host is equipped with a positioning device such as a GPS receiver from which it can read its current location. Given any physical location, there should be a predefined mapping from the location to its grid coordinate.

In each grid, one host will be elected as the *gateway* of the grid. The responsibility of gateway hosts is to propagate geocast packets to neighboring grids. All non-gateway hosts are not responsible for these jobs unless they are sources. For maintaining the quality of routes, we also suggest that the gateway host of a grid should be the one nearest to the physical center of the grid.

One thing which is unspecified above, but will affect the performance of our protocol, is d (the side length of grids). Let r be the transmission distance of a radio signal. We discuss six possibilities of choose d:

1. d is too large: The radio signal of a gateway host will have difficulty in reaching places outside of the grid, and thus a gateway-to-gateway communication is unlikely to succeed. So a d which is too large is unrealistic. (See Fig. 3(a), which shows the case of $d = 2r$.)

2. $d = r$: This represents the maximum value of d such that the gateways of two neighboring grids can talk to each other if they are located precisely at the centers of grids. (See Fig. 3(b).)

3. $d = \frac{2r}{\sqrt{10}}$: This represents the maximum value of d such that a gateway located at the center of a grid is capable of talking to any gateway of its 4 neighboring grids. (See Fig. 3(c).)

4. $d = \frac{\sqrt{2}r}{3}$: This represents the maximum value of d such that a gateway located at the center of a grid is capable of talking to any gateway of its 8 neighboring grids. (See Fig. 3(d).)

5. $d = \frac{r}{2\sqrt{2}}$: This represents the maximum value of d such that a gateway located at *any* position of a grid is capable of talking to any gateway of its 8 neighboring grids. (See Fig. 3(e).)

6. d is too small: This means that there will be very few, or sometimes no, mobile hosts resident in a grid. The chance of a mobile host becoming a gateway is high. In the extreme case, when d is infinitely small, there will be infinitely many grid and each host is the gateway of its own grid. In fact, this extreme case converges to the situation where there is no concept of grids, since each host will be responsible of forwarding route discovery and data packets. (See Fig. 3(f), which shows the case of $d = \frac{r}{10}$.)

The above discussion implies that a smaller value of d will lead to higher connectivity between neighboring grids. However, a smaller d also means more number of leaders in the network, which in turn implies a higher overhead of delivering packet and more broadcast storm. So there exist some tradeoffs in choosing a good value of d.

3.2 Protocol Details

The main features of our GeoGRID are as follows. First, we will use the locations of source and geocast region to confine the forwarding range. Second, instead of letting every host to forward data, we only allow gateway hosts to take this responsibility. In this paper, two versions of GeoGRID will be proposed, one called *flooding-based* and the other called *ticket-based*.

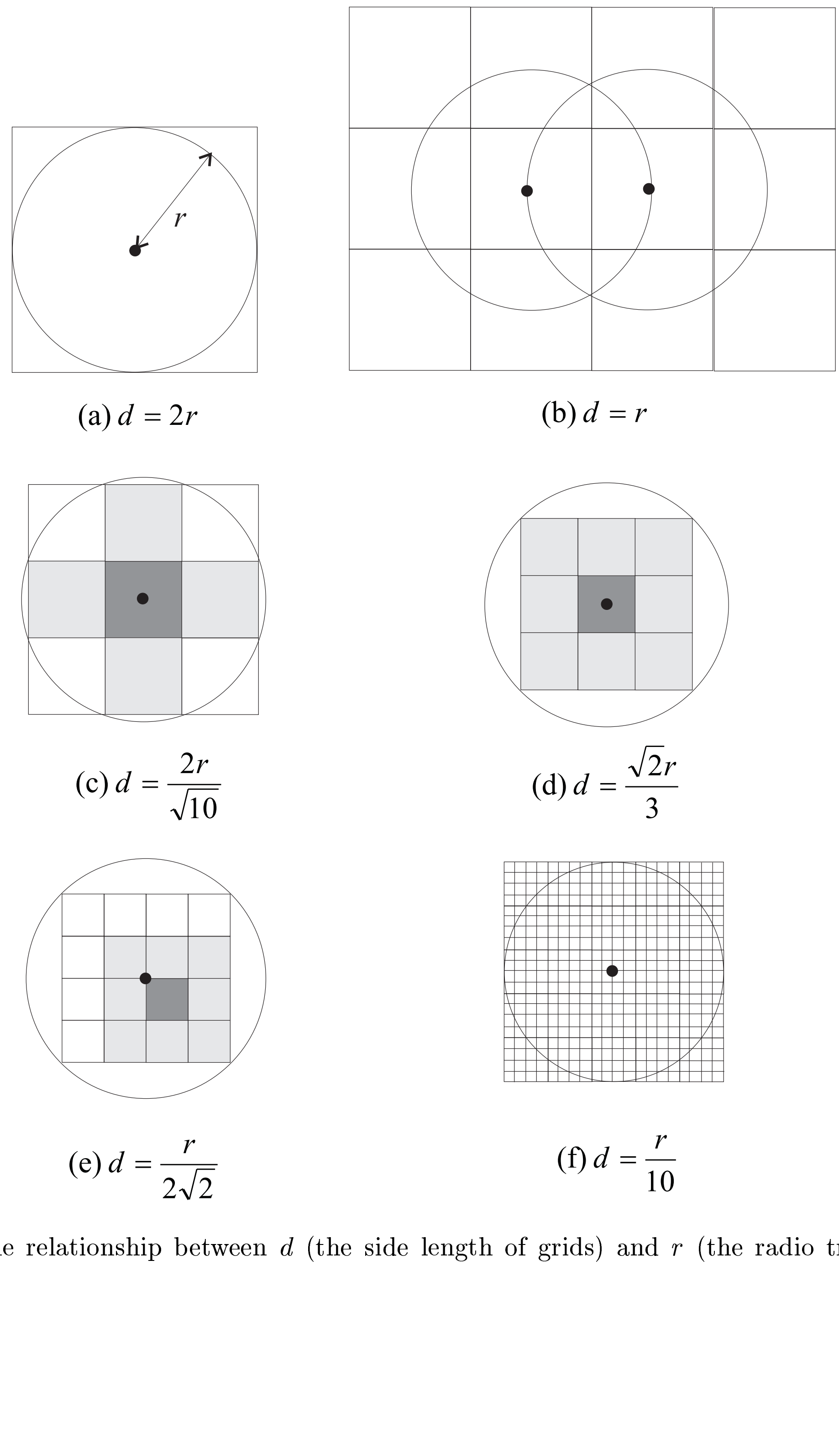

Fig. 3: The relationship between d (the side length of grids) and r (the radio transmission distance).

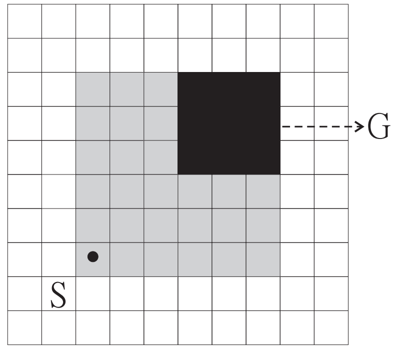

Fig. 4: The flooding region.

3.2.1 Flooding-Based GeoGRID

In the flooding-based approach, no spanning tree or routing path will be established prior to geocasting. Each node serving as a grid gateway within the flooding region will help forwarding geocast messages. All other hosts will not do so. Note that this is different from pure flooding, although the approach carries a name "flood". The flooding region is defined the same as that in [12].

When a node S wants to send a geocast message to a destination region G, a packet $DATA(S, id, G, R)$ will be sent, where

- id: the identification (or sequence number) of geocast message.
- R: the minimum rectangle that covers the grids of S and G (see Fig. 4 for an illustration). We call R the *flooding region*.

When a host X receives such a data packet, the following actions will be taken:

1. If X's current location is outside of R, it will discard the packet.
2. If X is a gateway and its current location is within R, it uses the tuple (S, id) to detect if this is a new packet (this is to avoid endless flooding of the same packet). If so, X will rebroadcast this packet; otherwise, it discards this packet.
3. If X is within the geocast destination G, it forwards this packet to the upper layer; otherwise, it discards this packet.

For example, in Fig. 5, hosts A, B, C, D, E, F, H, and I are the gateways of grids (1, 1), (2, 1), (2, 0), (3, 2), (3, 1), (4, 1), (2, 2), and (0, 1), respectively. Suppose host S initiates a geocast to the region G bounded by grids (3, 2), (5, 2), (5, 3), and (3, 3). Then the flooding region R will be the rectangle bounded by grids (1, 0), (5, 0), (5, 3), and (1, 3). When host B receives this packet for the first time, since it is within the flooding range, it will rebroadcast this packet. This is the same when E receives this packet. However, when host I receives this packet, it will ignore the packet as it is not within R. Finally, as D receives the packet, it will forward the packet to all other gateways in G, hoping to deliver the geocast message to all other hosts in G.

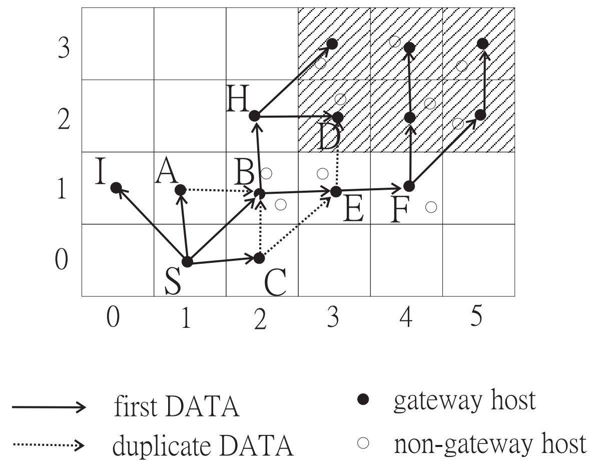

Fig. 5: A geocasting example by the flooding-based GeoGRID.

3.2.2 Ticket-Based GeoGRID

In the ticket-based approach, geocast messages are still forwarded by gateway hosts, but not all the gateways in the flooding region will do this job. The concept is similar to that in [3] — to avoid blind flooding, we will issue a number of tickets, each responsible of carrying one geocast message to the destination region. A geocasat message will be denoted by $DATA(S, id, G, R, n_1, t_1, n_2, t_2, n_3, t_3)$, where

- S: the source host.
- id: the identification of geocast message.
- G: the geocast region.
- R: the minimum rectangle that covers the grids of S and G.
- n_1, n_2, and n_3: three grids that are within the flooding region, are neighboring to the grid of the current sending host, and are closer to the destination region than the current sending host. Note that it is possible that there are less than three grids satisfying these conditions. If so, we simply fill these fields by $\emptyset$.
- t_1, t_2, and t_3: the numbers of the tickets issued to n_1, n_2, and n_3, respectively.

Observe that the number of tickets issued by the source node will proportionally reflect the geocasting overhead, but will affect the arrival rate of the geocast messages. In this paper, we propose to set up this value proportional to the size of the destination region. Specifically, assuming that the destination region is a rectangle of $m \times n$ grids, we will issue $m + n$ tickets from the source node. On a relaying host receiving k tickets, it will evenly divide these tickets to its neighboring grids that can satisfy the aforementioned conditions.

Now, suppose a gateway host X within the flooding region R receives a geocast packet containing k tickets for it. The following rules will be used.

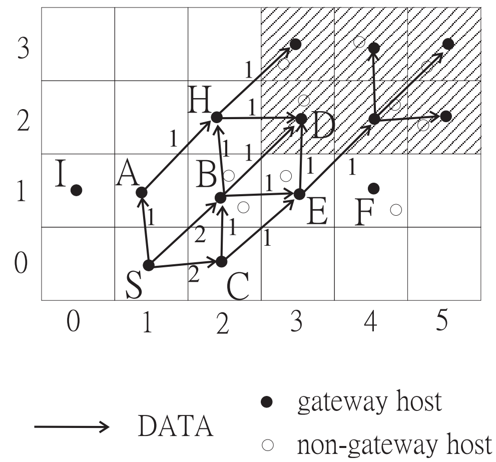

Fig. 6: A geocasting example by the ticket-based GeoGRID protocol.

- X is not within G: X will select from its neighboring grids that are closer to the destination region G and are within the flooding region R. Then X will forward (through broadcasting) the geocast message by evenly distributing its k tickets to these neighbors. Note that if this geocast message is a duplicate message but from a different neighboring grid, X will not discard this packet. Instead, X will still follow the above rule to forward the geocast message. This is to follow our original philosophy that each ticket is responsible of carrying one copy of the geocast message to the destination region.

- X is within G: Since the geocast packet has arrived at the destination region, X will always rebroadcast the packet (in hope of achieving a higher arrival rate).

An example is shown in Fig. 6. Five tickets are issued by the source host S with a geocast packet $DATA(S, id, G, R, (2, 0), 2, (2, 1), 2, (1, 1), 1)$. On the gateway host C receiving this packet, it may broadcast a packet $DATA(S, id, G, R, (2, 1), 1, (3, 1), 1, (3, 0), 0)$. For gateway host B, it may broadcast a packet $DATA(S, id, G, R, (2, 2), 1, (3, 2), 1, (3, 1), 0)$. After a while, when B receives C's packet, since there is a ticket for it, it has to rebroadcast the geocast message. Based on a round-robin rule, B may broadcast a packet $DATA(S, id, G, R, (2, 2), 0, (3, 2), 0, (3, 1), 1)$. On any gateway host within the destination region G (such as D) receiving the geocast packet for the first time, it should rebroadcast the packet.

3.3 Gateway Election

To maintain the gateway in each grid, an efficient solution for gateway election is needed. We list the following guidelines in developing a good election protocol:

- When a new gateway should be elected, the mobile host nearest to the physical center of a grid should be selected. Such a host will be more stable because it is likely to remain in the grid for longer time. Thus, the election procedure will be executed less frequently and the protocol will be more bandwidth-efficient.

- To avoid the ping-pong effect, once a mobile host is elected as the gateway, it will remain so until it moves out of the grid. Thus, when another gateway roams closer to the physical center of the grid, it will not be elected as a gateway until the earlier one leaves the grid.

Now, we formally develop our gateway election protocol, which is based on the result in [14].

1. Periodically, a gateway host should broadcast its existence by sending a $GATE(g, loc)$ packet, where g is its grid coordinate and loc is its current location.

2. Each mobile host should monitor the current gateway in its grid. If the $GATE$ packet is not heard for a predefined time period, it will broadcast a $BID(g, loc)$ packet, where g is its grid coordinate and loc is its current location. Upon the gateway host (if it is still alive and is in grid g) hearing the BID packet, it will reply a $GATE$ packet to reject the former's bid. Upon a non-gateway at a location closer to the physical center of the grid hearing the BID packet, it will reply a $BID(g, loc')$ packet to reject the former's bid, where loc' is the sending host's current location. If no such packets are received by the bidding host for a predefined time period, the bidding host will silently elect itself as the current gateway without sending any packet (but it still has the obligation to announce its existence by following rule 1).

3. When a gateway host leaves its current grid, it should broadcast a $RETIRE(g, T)$ packet, where g is the grid coordinate where it served as a gateway and T is the routing table at its hand. Every other host in this grid, on hearing this packet, will inherit the routing table T and take the same action as in rule 2 by sending BID packets to compete as a new gateway.

4. Each mobile host (including gateway and non-gateway) should monitor the existence of a gateway in each of its neighboring grids. When the mobile host roams into a new grid g in which it knows of no gateway existing, it will broadcast a $BID(g, loc)$ packet to compete as a gateway, where loc is its current location. Then rule 2 will take action if some hosts disagree with this bidding.

5. To eliminate the possibility of having multiple gateways in a grid, when a host who assumes itself as the gateway hears the $GATE$ packet from another host from a location closer to the physical center of its grid, it silently turns itself as a non-gateway without sending any packet.

Note that the last rule is necessary because broadcast is unreliable. Two BID packets may collide with each other without attention.

4 Experimental Results

4.1 Simulation Model

We have developed a simulator to evaluate the performance of our protocol. The results are compared to pure flooding and Ko's protocol [12]. Observing that the clustering protocol [8] can be easily used in place of flooding, we also make comparison to that. Specifically, two versions of the clustering protocol are used. The first version (called *Cluster-1* in the following) confines rebroadcasting of the geocast messages by only *cluster headers* and *gateways* (refer to the original work for these definitions). The second version (called *Cluster-2*) further tries to eliminate redundant gateways by limiting at most one gateway node between two neighboring clusters. Also, the concept of forwarding zone in [12] will be used in them.

A MANET in a physical area of size $1000m \times 1000m$ with $50 \sim 500$ mobile hosts was simulated. Each mobile host could roam around with a speed of 0, 30, and, 60 km/hr. In every 0.5 second, a mobile changed its roaming direction with a randomly chosen one. Each mobile host had a transmission range of 300 meters. The grid size was fixed at $d = \frac{\sqrt{2}r}{3}$ (due to our earlier experience in [14]).

The transmission speed of mobile hosts was 2Mbit/sec. A medium access similar to the IEEE 802.11 was adopted. Since medium access was simulated, the potential problems such as hidden terminals and collisions could be accurately caught from the simulation. Geocast packets are of size $6 \sim 12$ Kbit. Each simulation run lasted for 500 seconds. In each run, the source was chosen randomly, but the geocast region was fixed as a square of 100m $\times$ 100m $\sim$ 300m $\times$ 300m. Then the source performed one geocast per second.

4.2 Observed Results

Three metrics are used in our comparison:

- arrival rate: the number of hosts receiving the geocast message divided by the total number of hosts resident in the geocast region.
- delivery cost: the number of transmissions per geocast request.
- control cost: the number of packets to maintain grid gateways in GeoGRID-F and GeoGRID-T, or to maintain cluster structures in Cluster-1 and Cluster-2.

In Fig. 7, we show the arrival rate at different host densities. Generally speaking, GeoGRID-F performs the best, which is followed by Cluster-2, GeoGRID-T, Cluster-1, Ko, and then flooding. The number of mobile hosts has little effect on GeoGRID-F, GeoGRID-T, and Cluster-2, because only hosts with special roles are allowed to rebroadcast geocast messages. On the contrary, the other protocols will degrade seriously as the environment is crowded. Also note that the curve for Ko is slightly different from that in the original work [12], probably because packet collisions were not simulated therein.

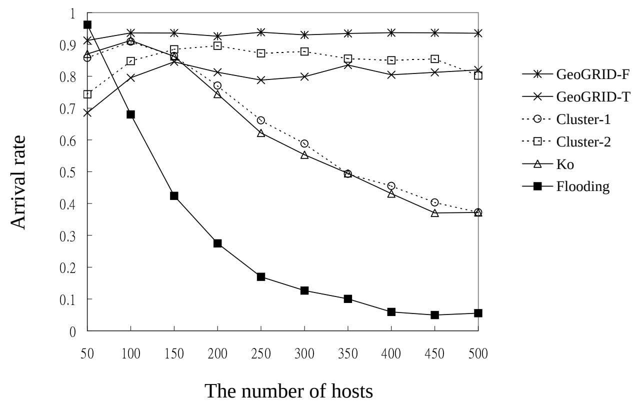

Fig. 7: Arrival rate vs. total number of mobile hosts, where host speed = 30 km/hr, geocast range = 300m × 300m, and data packet size = 12 Kb.

In Fig. 8, we vary the geocast range to observe the arrival rate. Both Cluster-1 and Ko will be affected by the geocast range. This is because more hosts will try to do rebroadcasting, thus causing more serious broadcast storm.

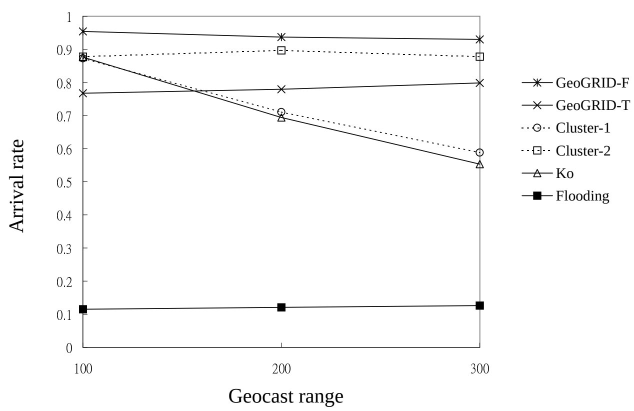

Fig. 8: Arrival rate vs. geocast range, where host speed = 30 km/hr, number of hosts = 300, and data packet size = 12 Kb.

Fig. 9 shows the effect of host mobility on the arrival rate. Consistently in all protocols, the arrival rate only decreases slightly.

In Fig. 10, we show the effect of data packet size on arrival rate. A longer packet could be more vulnerable to packet collision. As can be seen, only GeoGRID-F, GeoGRID-T, and Cluster-2 are insensitive to packet size. Again, GeoGRID-F performs the best among all protocols being compared.

In Fig. 11, Fig. 12, Fig. 13, and Fig. 14, we show the delivery cost by varying the aforementioned parameters. Generally speaking, the cost of flooding is highest, which is followed by

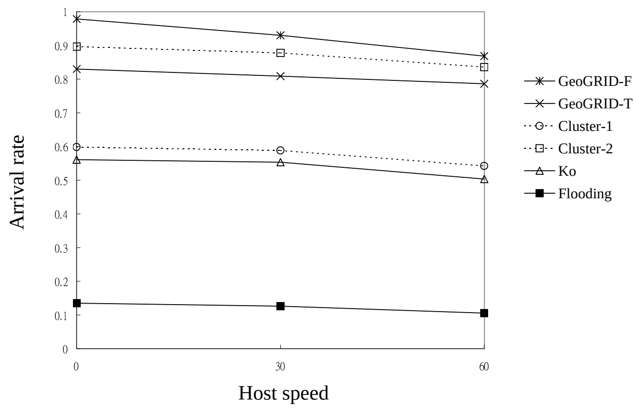

Fig. 9: Arrival rate vs. host speed, where number of mobile hosts = 300, geocast range = 300m × 300m, and data packet size = 12 Kb.

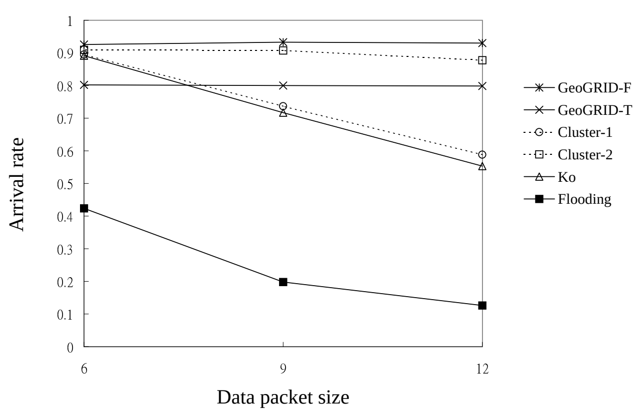

Fig. 10: Arrival rate vs. data packet size, where number of mobile hosts = 300, geocast range = 300m × 300m, and host speed = 30 km/hr.

Ko, Cluster-1, Cluster-2, GeoGRID-F, and then GeoGRID-T. Combining these observations, we would recommend GeoGRID-F as the best candidate for geocast because it not only has higher arrival rate, but also incurs less delivery cost.

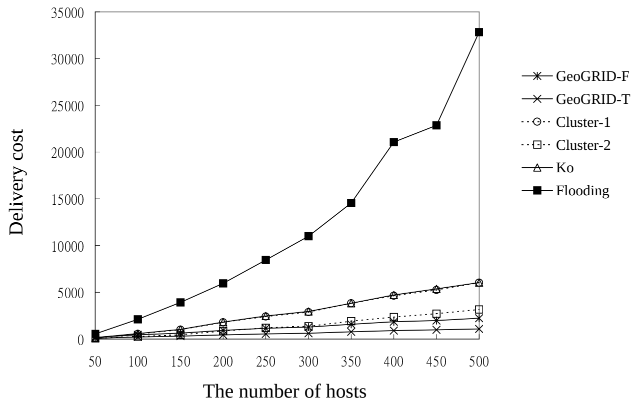

Fig. 11: Delivery cost vs. total number of mobile hosts, where host speed = 30 km/hr, geocast range = 300m × 300m, and data packet size = 12 Kb.

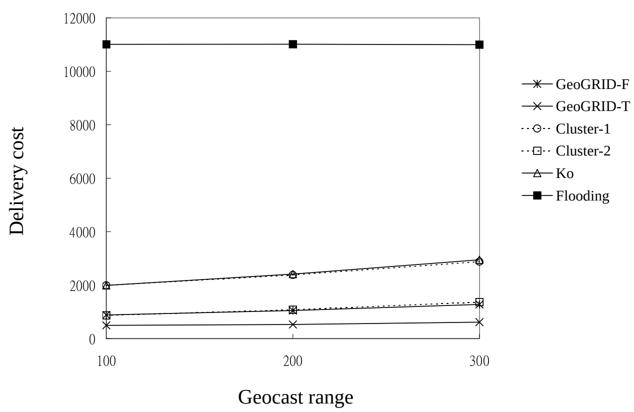

Fig. 12: Delivery cost vs. geocast range, where host speed = 30 km/hr, number of mobile hosts = 300, and data packet size = 12 Kb.

In addition to delivery cost, GRID-T, GRID-F, Cluster-1, and Cluster-2 have to send extra control packets to elect grid gateways or maintain cluster structures. Fig. 15 shows the control costs at different host densities. The result indicates that electing gateways is less costly than maintaining clusters. Similar result is shown in Fig. 16 by varying the host speed. Still, electing gateways is less costly. Finally, we comment that the control cost is the same for GeoGRID-F and GeoGRID-T because it is irrelevant to the geocasting strategy.

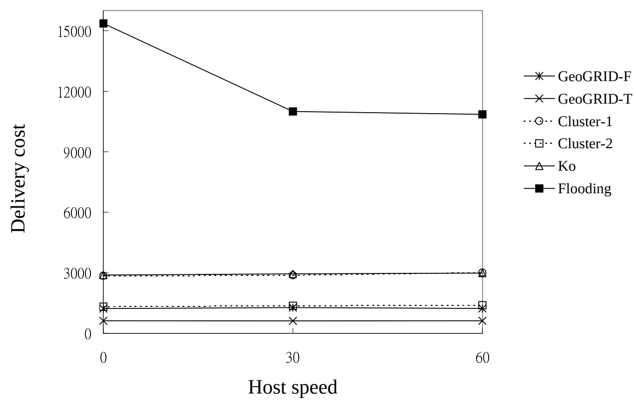

Fig. 13: Delivery cost vs. host speed, where number of mobile hosts = 300, geocast range = 300m × 300m, and data packet size = 12 Kb.

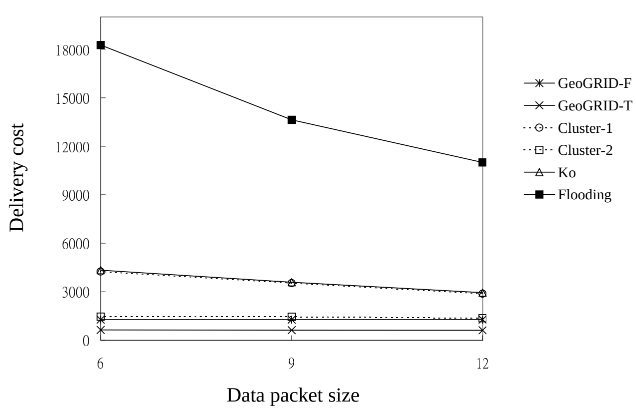

Fig. 14: Delivery cost vs. data packet size, where number of mobile hosts = 300, geocast range = 300m × 300m, and host speed = 30 km/hr.

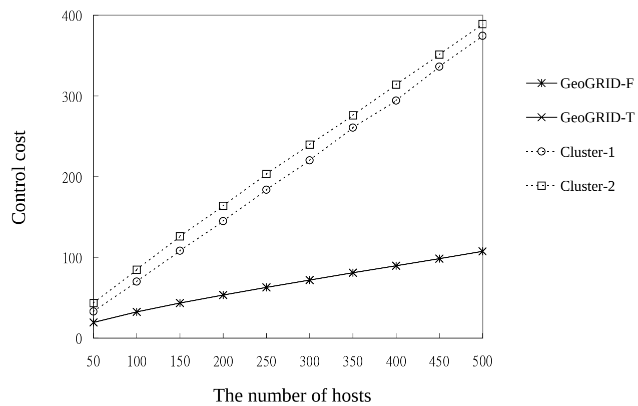

Fig. 15: Control cost vs. number of mobile hosts, where host speed = 30 km/hr, geocast range = 300m × 300m, and data packet size = 12 Kb.

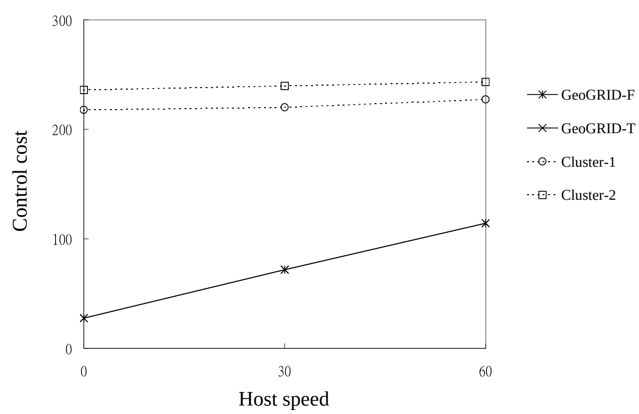

Fig. 16: Control cost vs. host speed, where number of mobile hosts = 300, geocast range = 300m × 300m, and data packet size = 12 Kb.

5 Conclusions

In this paper, we have presented a new geocasting protocol for MANETs. We have successfully applied the grid structure to eliminate redundant retransmission of geocasting messages, while at the same time maintaining a high arrival rate of geocasting messages. This is achieved by delegating the packet-forwarding responsibility to only one mobile host (if existing) in each grid. In addition to these advantages, through verification of simulations, our protocol also demonstrates a good behavior in that it is quite insensitive to host density, host speed, size of geocast region, and size of geocast packet.

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