Geometry-driven Scheme for Geocast Routing in Mobile Ad Hoc Networks*

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Abstract—**This paper considers the problem of geocasting in mobile ad hoc networks. Geocasting, a variation on the notion of multicasting, is a mechanism to deliver messages of interest to all nodes within a certain geographical target region. Although several geocasting protocols have already been proposed for mobile ad hoc networks, with the goal of achieving an efficient message delivery, most of these algorithms consider a "single" target region only and therefore multiple transmissions should be initiated separately by the message source when more than one target regions need to receive the same geocast messages. This causes significant performance degradation, especially as the number of geocast regions increase. To solve this problem, we propose a novel scheme driven by geometry, named GGP (Geometry-driven Geocasting Protocol). In this scheme, the geometric concept of "Fermat point" is utilized to determine the optimal junction point among multiple geocast regions from the source node, and hence to reduce the overhead of message delivery, while maintaining a high delivery ratio.**

I. Introduction

With cheap and small form factor of GPS receivers, it is likely that location information of network nodes or regions will become easily available. Geocasting is a mechanism based on location information, which delivers messages of interest to any nodes within a certain geographical region. It is a variation of multicasting, but there is a significant difference between these two approaches. In a traditional multicasting, if a node wants to be a member of a certain multicast group, it has to explicitly join the group. On the other hand, in geocasting, a node automatically becomes a member if its geographical location belongs to the region associated with the geocast group - this region is referred as the *geocast region* [2]. Thus, the set of nodes in the geocast region is said to form the *geocast group*. With a geocasting protocol, when a packet arrives at any one member node of the target geocast group, a local flooding operation is followed to deliver the packet to all members of the group.

A number of geocast protocols have been developed [3], but most of them consider only a "single" target region. However, there are various scenarios in which we need to send the same information to multiple geocast regions; for example, a traffic announcement towards multiple congested areas, a local advertisement for many branch stores in different sites, and an urgent order by a commanding officer on the battlefield. Using the conventional geocast protocols for these scenarios, the same message needs to be sent repeatedly towards each target region as illustrated in Fig. 1(a). It may cause some inefficiency in terms of network traffic and latency. Especially, such an inefficiency problem becomes severe as the number of target regions increases, even if it would be clearly better compared to multiple unicasts. Note that, a delivery with multiple unicasts is the simplest way to serve multiple target nodes, but possibly wasting too much network resources because a source needs to create multiple unicast packets[1] for each node (See Fig. 1(b)).

In this paper, we propose a novel scheme driven by geometry, named GGP (Geometry-driven Geocasting Protocol) which works efficiently for sending the same message to multiple geocast regions. Our protocol, as shown in Fig. 1(c), creates a tree-like structure that includes a shared path to reach multiple target regions based on the concept of "Fermat point" [4, 12]. The Fermat point is defined as a point within a triangle for which the sum of its distances from the vertices of the triangle becomes a minimum. Thus, the path through the Fermat point guarantees to become an optimal one starting from a source node destined to the two different target regions. We use this shared path for delivering packets towards these two different geocast regions *at once*. As a result, our scheme reduces the network traffic and the packet delivery latency. We generalize this algorithm, in order to apply for more complicated scenarios with more than two target regions.

The rest of the paper is organized as follows. Related Works are described in Section II. Section III introduces our proposed scheme followed by ns-2 simulation results in Section IV. We conclude in Section V.

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[1] We will use the terms *message* and *packet* interchangeably.

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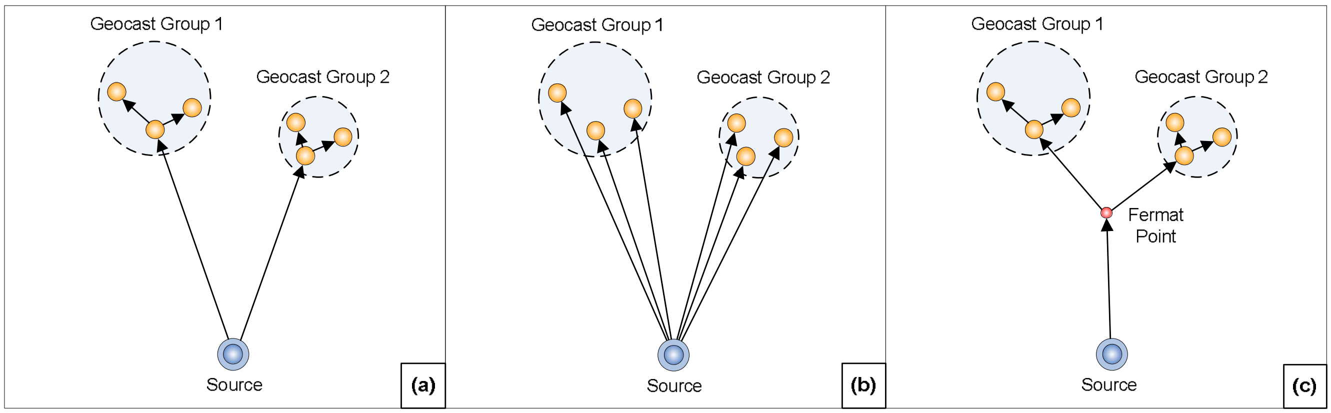


(a) Conventional Geocasting (b) Multiple Unicasts (c) The proposed GGP

Fig. 1. Different message delivery strategies for multiple targets

II. Related Works

The early notion of using location information for ad hoc routing is introduced in [5]. In this paper, Ko and Vaidya reduce the network overhead during route discovery phase by restricting packet forwarding to the "request zone" based on geographical information of the source and destination nodes. This approach is helpful to alleviate network congestion by reducing a number of broadcast packets. Based on the similar idea given in [5], the Location Based Multicast (LBM) [2] scheme presents a variance of flooding by constraining geocast packets implicitly or explicitly within a certain geographical area named "forwarding zone." In order to reduce control packet overheads further, [6, 7] utilize a unicast routing protocol when a packet is delivered to any node in the target region, and then the packet is locally flooded within the region. However, it generates additional control packets to construct a routing topology.

In [8], Seada et al. use the greedy forwarding approach [9] for a packet delivery towards a geocast region. With the greedy forwarding scheme, each node receiving a packet is required to select a neighboring node that is closest to the destination of the packet as the next hop. Forwarding in this manner follows successively closer geographic hops, until the destination is reached. A greedy forwarding itself had been introduced earlier in [10]. This approach is efficient from the aspect of reducing the network overhead because it does not generate any additional control packets to construct a routing topology. The authors in [8] mainly focus on avoiding obstacles that hinder packet delivery within the target geocast region in order to reliably deliver packets.

In [11], Chang et al. proposed a geocast protocol having a specialty of evading obstacles. This protocol is based on clustering and a hierarchical network design, where each cell (cluster) is shaped as a hexagon. This paper considers not only a single destination but also multiple destinations, for which each node selects one direction among the six neighboring cells that has the smallest hop (cell) count to the destinations. In a certain intermediate cell, if the locally optimal directions for each destination are different, the routing path splits. This algorithm simply makes a shared tree for multiple destinations, but it does not promise the global optimal path, and sometimes it shows the obviously inefficient path selection, because the choice of next hop is restricted by cellular shape. Moreover, this scheme results in the additional overhead for a cell management.

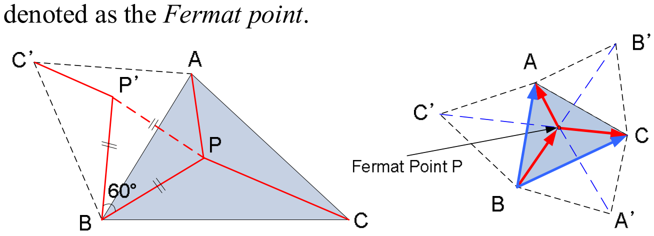
III. Proposed Scheme

Before presenting our proposed scheme, GGP (Geometry-Driven Geocasting Protocol), we examine the Fermat problem that is well-known in the area of geometry [4, 12].

A. *The geometric concept of "Fermat Point"*

Basically the Fermat problem is to find a solution for the following question: "what is the point such that the sum of its distances from the vertices of a triangle is a minimum?"

Problem Definition. Let us assume that A, B and C are three given points as shown in Fig. 2(a). In the plane of the three given points, *Fermat problem* is to find the point P such that $\overline{PA}+\overline{PB}+\overline{PC}$ becomes a minimum. This point is then denoted as the *Fermat point*.



(a) (b)

Fig. 2. The definition and solution of the Fermat point problem

Solution. In ΔABC in Fig. 2(a), select a point P and connect it with three vertices A, B, and C. Rotate ΔABP 60° around B into the position $\Delta C'BP'$. By construction, $\Delta BPP'$ is equilateral, $\overline{PA}=\overline{C'P'}$, and $\overline{PB}=\overline{P'B}$. Thus, we have $\overline{PA}+\overline{PB}+\overline{PC}=\overline{C'P'}+\overline{P'P}+\overline{PC}$. As the image of A under the rotation, the position of C' does not depend on P. Also,

$\overline{PA}+\overline{PB}+\overline{PC} \geq \overline{CC'}$ because the broken line $\overline{CPP'C'}$ is not shorter than the straight line $\overline{CC'}$. Therefore, $\overline{PA}+\overline{PB}+\overline{PC}$ reaches its minimum iff P lies on $\overline{CC'}$. Consequently, the point P solves the Fermat problem, so it is the Fermat point. For this P, $\Delta ABC'$ is also equilateral because $\overline{AB}=\overline{C'B}$ and $\angle ABC' = 60°$. Similarly, we can draw other straight lines which connect vertices of the triangle with the opposite vertices of equilateral triangles. These straight lines cross at one point as shown in Fig. 2(b). ■

B. Geometry-Driven Geocasting Protocol (GGP)

Overall, the proposed GGP consists of two phases: *a greedy forwarding* and *a regional flooding*. First, a greedy forwarding is performed from a source to any node in the geocast region. A regional flooding is then employed to deliver the messages to all nodes within the region. We mainly describe the greedy forwarding phase and discuss about how a junction (i.e., the Fermat point) can be chosen to construct a more effective shared path, through which an efficient geocast delivery for multiple target regions can be achieved.

For simplicity, we consider the case with only two geocast regions as shown in Fig. 3. First, we construct a virtual triangle based on the geographical position of a source node and the two central points of the target regions. With this triangle, the source node computes the Fermat point as explained in the previous section. Then, it sends packets toward the location of this Fermat point using a greedy forwarding. Upon receiving the packet, each node compares the location of the Fermat point embedded in the packet with its own and neighbors' location. (Neighbor information can be achieved from periodic hello messages.) If there exists any neighbor closer to the Fermat point, it forwards the packet to that neighbor. Otherwise, the node itself becomes the Fermat point and forwards the packet to each target region separately. By theory, the path constructed based on the original Fermat point is guaranteed to be optimal. However, there is a possibility such that no nodes are located on the exact position of the Fermat point. In this case, any node closest to the Fermat point substitutes for the Fermat point. Therefore, our algorithm always makes an efficient shared path which is near to optimal.

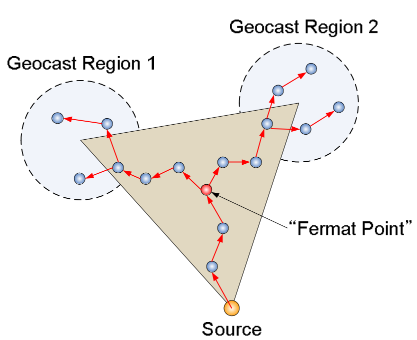


Fig. 3. Constructing the Fermat point based, shared path (Number of geocast regions = 2)

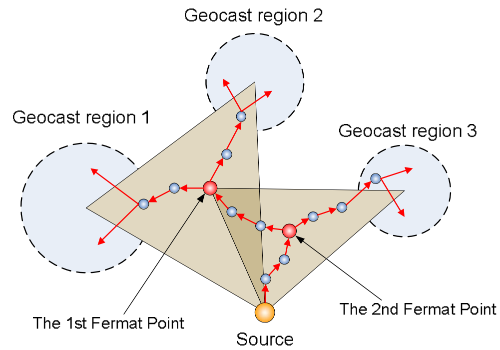


Fig. 4. Expanding a shared tree with a heuristic of chaining consecutive Fermat points (Number of geocast regions = 3)

Now, we generalize our scheme to support more than two geocast regions. The basic idea is to construct a tree by chaining the consecutive Fermat points. At first, we randomly select the first geocast region followed by the next region having the smallest angle between the first geocast region, the source and itself. Consequently, the given geocast regions are sorted clockwise from the first region. Let us consider Fig. 4, where the first Fermat point computed by using first two geocast regions and the source is given, and there is one more geocast region (i.e., Geocast region 3). For this scenario, we construct another triangle with the source node, the first Fermat point and the central point of the third geocast region. Based on this triangle, a source node computes the second Fermat point. As a result, we get a shared tree by connecting these two Fermat points. Thus, using this expanded shared tree towards more than two geocast regions is likely to be more efficient than using multiple separated paths towards each geocast region.[2]

One possible problem with such an expanded shared tree is that it may result in some unbalanced tree when there are many geocast regions surrounding a source node. Actually, the solution of the Fermat problem is known to work only if any internal angle of the triangle is equal or less than 120 degrees. To solve this problem, we limit the size of any shared tree rooted at a source node such that an internal angle never exceeds 120 degrees. Thus, in the worst case, three big tree branches rooted at a source will be generated to cover all the target regions spread out in any direction from the source.

Fig. 5 illustrates the detailed operation of our scheme. Fig. 5(a) shows an initial topology with the three geocast regions named A, B, and C. F1 is the first Fermat point based on geocast regions A, B, and the source node. F2 represents the second Fermat point based on the first Fermat point F1, geocast region C, and the source node. Now, the source node makes a *forwarding list* including position information of all target geocast regions and Fermat points. In this example, the forwarding list consists of the sequence F2, C, F1, B and A (see, Fig. 5(b)). A geocast message sent by a source will reach

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[2] Actually, there is a method to achieve the Fermat points in the case of a polygon having more than three vertices. However, it is too complicated to apply in this way, because the degree of the equation will be too high. Therefore, as an alternative, we design a heuristic scheme of chaining consecutive Fermat points in a reverse order.

node X located either on the exact position of the Fermat point F2 or in the proximity of it. At node X, the geocast packet having the forwarding list will be split info two as shown in Fig. 5(c). One of the split packets will be split again at node Y, whose (x, y) coordinate are equal or approximate to that of the first Fermat point F1. (see in Fig. 5(d)). Hence, all geocast regions A, B, C will finally get the packet.

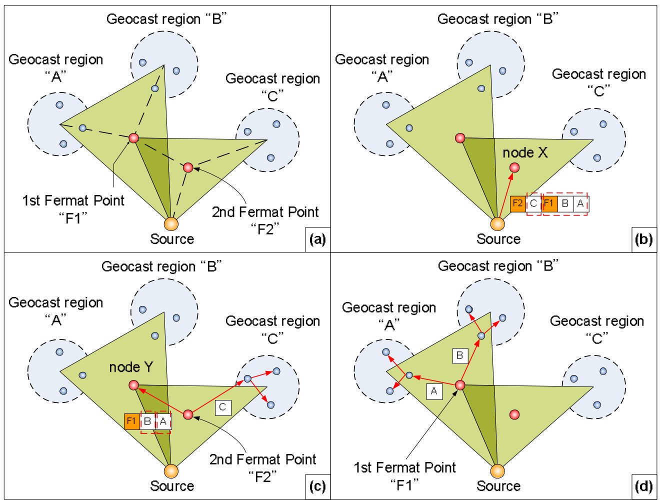


Fig. 5. Detailed operation of the proposed GGP

IV. PERFORMANCE EVALUATION

A. Simulation Environment

For the evaluation purpose, the proposed GGP is compared to the pure geocast flooding and the LBM [2] algorithms. The pure geocast flooding is based on a network-wide flooding of data packets, whereas the LBM scheme limits its flooding within the smallest rectangular area that includes both source node and a geocast region.

We performed a simulation study using ns-2 [13]. In our simulation model, 200 nodes are randomly deployed in $1500m \times 1500m$ square area. We designate one source node positioned at the corner of network. While the source node is immobile, other nodes can move according to a random movement pattern with maximum speed of 5*m/s* without pause. A geocast region is circular in shape with the radius of 250*m*. In this network environment, the average number of geocast group members in each geocast region is observed to be around 12. During simulation, one data packet is generated per second from the source to the target regions with fixed-size payload of 512 bytes.

Since both geocast flooding and the LBM schemes have no consideration for the multiple regions, the source node transmits packets to each geocast region separately with a time interval set to α second. This α value can affect on a delivery ratio and delay time, because a small value of α may cause packets to collide, whereas a large value of α may increase delay. In our proposed GGP, this time interval is also used when the packet splits at the Fermat point. We performed experiments to find the appropriate value for α. Total simulation time is 900 seconds and we repeat each scenario five times with different random seed numbers.

We evaluate our scheme using the following metrics. *Packet delivery ratio* is defined as a ratio of the number of geocast group members receiving data packets to the number of group members which were supposed to receive the packet. The delay time is measured as a difference in time from when the source generates a data packet to when a geocast group member receives it. We report the *average delay time* over all the geocast source and receiver pairs. *Normalized packet overhead* is defined as the total size of all transmitted data and control packets divided by the total number of nodes and simulation time. This metric reflects the total routing load involved in delivering geocast data and hence protocol efficiency.

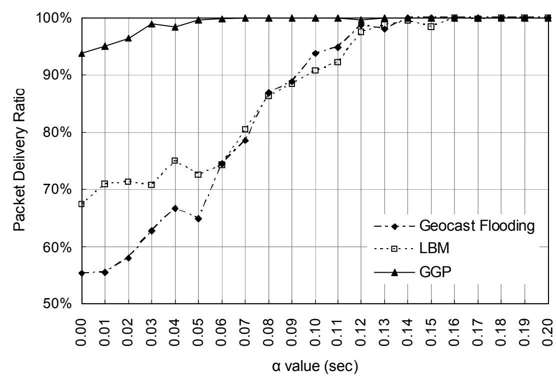
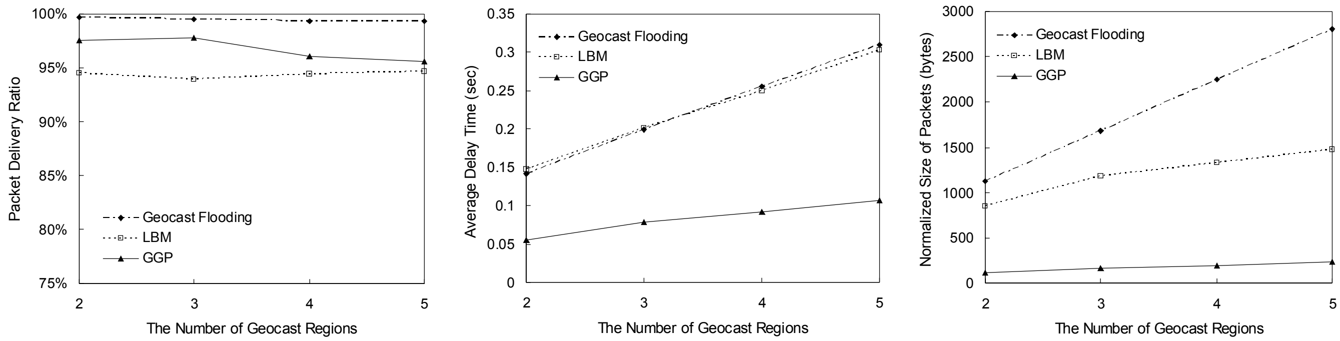


Fig. 6. Packet Delivery Ratio versus α value (static network)

B. Simulation Results

First, we examine how the time interval α influences the performance in each protocol. We change the α value from 0 to 0.2 seconds with 0.01 interval. Total geocast regions used in this simulation are 5 and all nodes are assumed to be static. In Fig. 6, the packet delivery ratio of GGP is always over 98% when the α value is larger than or equal to 0.03 seconds. However, for geocast flooding and LBM, the packet delivery ratio starts to reach over 98% when the α value is equal to 0.12. This difference is the outcome of the packet overhead generated in the network, and hence the different possibilities of packet collision. LBM produces fewer packets than geocast flooding, so LBM shows a higher delivery ratio than geocast flooding with the lower α values (e.g., below 0.05 seconds). Moreover, GGP utilizes a unicast packet forwarding so the packet overhead in GGP is mush less than others. According to this result, we decide to have 0.03 seconds of α value for GGP and 0.12 seconds of α value for geocast flooding and LBM.



(a) Packet Delivery Ratio (b) Average Delay Time (c) Normalized Packet Overhead

Fig. 7. Simulation Results (mobile network)

We evaluated our GGP with a variation of the number of geocast regions from 2 to 5. Fig. 7(a) presents the packet delivery ratio as a function of the number of geocast region. In GGP, the packet delivery ratio is always over 95%, which is slightly less than geocast flooding. However, LBM goes down below 95%. That is because δ parameter which is used to extend the forwarding zone in LBM. LBM could improve delivery ratio with larger δ value, but the packet overhead is also increased. We set δ to 50*m* as in [11]. With this δ value, the packet delivery ratio of LBM is slightly less than geocast flooding and GGP. This result shows that the proposed GGP is much reliable to deliver geocast packets.

In Fig. 7(b), we observe that the average delay time in GGP is smaller than that of the LBM and geocast flooding by 0.2 seconds. The difference of delay time becomes larger as the number of geocast region increases.

The normalized packet overhead as a function of the number of geocast region is shown in Fig. 7(c). In this figure, the packet overhead of GGP includes hello messages required in the process of a neighbor discovery. However, these hello messages are very small size, so they can be assumed to take relatively small portion of network bandwidth. In the best case, GGP produces less than 1/10 and 1/7 packets compared to geocast flooding and LBM respectively. Such an improvement can be achieved because GGP uses an efficient shared path for multiple geocast regions and therefore a frequency of packet generation by source can be significantly reduced.

V. CONCLUSION

Previous research on geocast protocols pays little attention for multiple geocast regions. These solutions are inefficient and cause unnecessary network overhead when applied to the problem of providing geocast services to multiple regions. To overcome this problem, we propose a novel geocast scheme named GGP (Geometry-driven Geocasting Protocol). The basic idea behind this protocol is to create a shared tree to reach multiple geocast regions based on the Fermat point. Through simulations, we show that our scheme is not only reliable in the aspect of packet delivery, but also reduces network overhead and latency significantly. Moreover, the proposed scheme exhibits good scalability characteristics for increasing number of geocast regions. GGP is useful in many applications and scenarios, and reduces overall routing cost. Ongoing work includes finding solutions for the evading obstacles, and exploring other methods of chaining Fermat points.

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