A Multi-Destination Obstacle-Free Geocasting Protocol for Ad Hoc Networks

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***Abstract*—Mobile Ad Hoc networks (MANET) have no infrastructure, with each mobile host acting as a router. The MANET environment contains unpredictable obstacles, such as mountains, lakes, buildings, or subregion without any host, impeding or blocking message relay. This study proposes a geocasting protocol for sending short message from a source host to multiple geocasting regions in Ad Hoc networks. The proposed protocol establishes share path for multiple geocasting regions so that the bandwidth consumption could be reduced. The developed protocol also keeps messages away from unpredictable obstacles and creates a small flooding region. Experimental results show that a source host can send a short message to all hosts located in multiple geographical areas with a high success rate and low flooding overhead.**

Keywords- short message; Geocasting; obstacle; Cellular-Based Management;

I. INTRODUCTION

An Ad Hoc network consists of mobile hosts, providing low cost and highly mobile communications. In contrast to a static network, Ad Hoc networks have no infrastructure, with each mobile host acting as a router, relaying information from one neighbor to others. Packet flooding is extensively used to establish a routing path from the source host to the destination. By considering all possible paths linking the source and destination, the source host can ascertain the shortest communication path. Ni [5] presented the problem of broadcasting storms and revealed the negative effects of the flooding operation. Various cluster-based protocols [3][6][7][8][13] have been developed to alleviate flooding, with the host in each partitioned cluster voting for a header to manage the cluster. Hosts wishing to establish communication paths should first send a request packet to their cluster manager, and the manager will then relay the packet to neighboring managers through manager-based flooding until the manager of the destination host is found. Cluster based protocols thus alleviate flooding, but increase management overheads.

Some other location-aware protocols [1][2] use GPS (Global Positioning System) to provide location information for establishing a routing path. The MANET is geographically partitioned into several disjoint and equally sized cell regions. The host can then use GPS to identify which grid it is located in. Within each cell, the host located closest to the center of the cell is selected as a manager, and handles the information of all the other hosts located in that cell. The manager is responsible for exchanging information or communications with managers of neighboring grids. When a source host wishes to establish a routing path to a destination host located in a different cell, the source host first issues a request to its manager. The routing path is then constructed by executing the manager-level flooding operation. In [12], the authors compare grid, triangular, and cellular shapes and illustrate that cellular-based partition schemes generate fewer flooding packets during path construction. To alleviate flooding, the geocasting protocols proposed herein are developed based on the management model proposed in [12].

Different from unicast or multicast service, geocasting service is defined by sending messages from the source to all hosts located in one or more specific geographical regions. Previous works [9][10][11][14][15], assumed that each host is equipped with a GPS that can determine its geographical position. Meanwhile, the source host is capable of defining specific geocasting regions and all hosts located in these regions are considered to be receivers. Ad hoc networks, contain unpredictable obstacles, such as mountains, lakes, buildings, or subregion without any host. These obstacles will impede or block message relay. Message flooding from source to the geocasting region is a simple method of overcoming them. However, message spread from the source host to the geocasting region is very costly, and creates serious redundancy, contention, and collision[5]. In [17], a geocasting protocol (OFGRP) for single destination has been proposed. OFGRP keeps messages away from obstacles by creating a very small flooding region. Even in cases involving unpredictable obstacles, OFGRP relays the message from the source host to all hosts in a single destination region with a high success rate and low flooding cost. However, in case of considering multiple destination regions, protocol proposed in [17] will establish individual path from source to each geocasting region, without sharing common link. It causes more bandwidth consumption and collision. Obstacle free share path for the multiple destinations should be constructed so that the bandwidth consumption could be reduced.

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This study focuses mainly on how to deviate from the unpredictable obstacle regions and create a shared and small flooding region so that the message can be successfully relayed from source host to all hosts in the destination regions. The multi-destination geocasting problem with more than two disconnected destination regions is investigated herein. To decrease the size of the flooding region, shared flooding regions must be created so that path from source to some destination regions can share the same flooding region. The OFMGP(Obstacle-Free Muti-destination Geocasting Protocol) is proposed for relaying messages from the source to all hosts located in a set of disconnected geographical regions. Simulations are also conducted to measure the performance in terms of success rate, number of flooding packets, and the flooding regions in multi-destination geocasting protocols.

The rest of this investigation is organized as follow. Some rules used in OFMGP is presented in Section 2. Section 3 then introduces the OFMGP for multi-destination geocasting problem. Meanwhile, Section 4 evaluates the performance of OFMGP in comparison with previous works. Conclusions and suggestions for future works are finally presented in Section 5.

II. OFSTACLE-FREE RULES

This section illustrates the rules to overcome the obstacles and to reduce the flooding region. The proposed obstacle-free rules will be applied in OFMGP. The MANET is assumed to be partitioned according to location information. A lot of partitioning schemes [4][12] have been proposed to reduce the flooding overhead so that path can be constructed by executing fewer flooding operations. The partitioning scheme proposed in [12] is adopted herein. Two phases, the *reaching phase* and the *broadcasting phase* are considered to overcome the obstacle problem. In the *reaching phase*, the source host attempts to send the message to one host in the destination region. To keep away from the obstacles, the short message is flooded in a small region to ensure that the message can be sent to one host located in the destination region. During this phase, the size of the flooding region is dynamically convergent, following the shape of the obstacles. During the second phase, an attempt is made to broadcast to all hosts in the destination region. Since the destination region may contains some obstacle regions, messages sent by the host located in destination region may be blocked by obstacles. During the *broadcast* phase, message will be sent to all hosts located in destination region, regardless of the presence of unpredictable obstacles. The following first introduces the reaching phase protocol, then describes operations of the *broadcasting* phase.

A. Reaching Phase Rules

During the *reaching phase*, the source host tries to send the message to one host in the destination region. The source host first identifies the destination regions and then evaluates the center location of the destination region. Let C_s denote the cellular-ID of the cellular region located by the source host, and let C_d denote the cellular-ID of the center of the destination region. The shaded region in Fig. 1 indicates the destination region. In the reaching phase, the cellular region C_d is considered to be the destination. Managers that receive the short message will attempt to relay the message to the cellular region C_d.

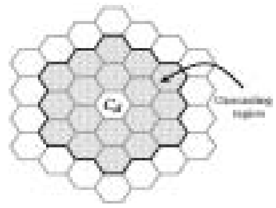


Figure 1. Center location of the geocasting Region.

To describe the reaching phase protocol, the *promising cellulars* and *managers* are defined. The *promising cellulars* of a cellular region are the three neighboring regons that are closest to the destination region C_d. Managers of the promising cellulars are called *promising managers*. The direction Dir_i that links the current cellular and the promising cellular is called *promising direction*. Fig. 2 illustrates the promising regions that have been numbered. A reaching phase protocol that can efficiently keep the short message away from obstacle and successfully relay the message to some hosts of destination region.

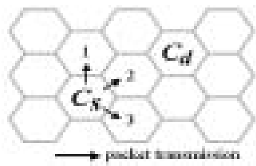


Figure 2. An example of promising cellular regions of C_s.

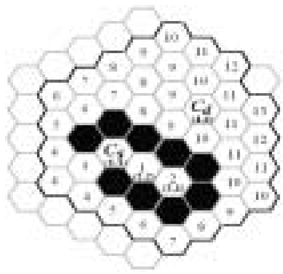


Figure 3. An example for executing reaching phase protocol in obstacle environment.

A manager, say *M*, that is not located in the destination region and receives the short message packet will handle the received message by the following *Reaching Phase Protocol*.

<u>*Reaching Phase Protocol*</u>

Rule 1: Manager *M* should relay the message to the promising managers.

Rule 2:If the three promising cellulars are obstacles, manager *M* should relay the message to the other three neighboring managers. If manager *M* receives an already received packet, it will not relay or broadcast the message again.

Rule 3:If Rules 1 and 2 fail, the message will be returned to the neighboring manager who sent the short message to manager M.

In Fig. 3, the message transmission order is numbered. The proposed rules in reaching phase could reduce the size of flooding region (the region surrounded by bold line as shown in Fig. 3) and the flooding region is automatically convergent.

B. Broadcasting Phase Rules

This subsection describes the second phase protocol, the broadcasting phase protocol, for delivering packets to all hosts located in the defined destination regions. Applying the reaching phase protocol, allows managers to relay the packet to a host in the destination regions, even if the obstacles create difficulties. Let the manager of the cellular regions surrounding the destination regions be the *around manager*. Once the *around manager* receives the packet, it checks the field of destination cellular ID, and executes the broadcasting protocol to help deliver the packet to all hosts in the destination regions. While some obstacles may exist within destination regions, we assume that no manager will be fully surrounded by obstacles and unable to communicate with any other manager. During the broadcasting phase, the destination regions are treated as a large virtual obstacle region. Let M_a denote the *around manager*, while M_d represents the manager located in the destination regions. Once M_a or M_d receive the "*forwarding*" packet, they initiate the following *broadcasting protocol*.

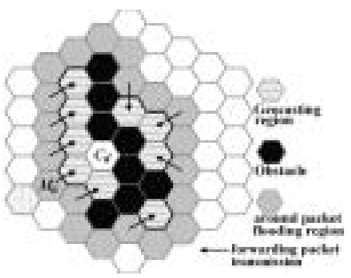


Figure 4. Operation of broadcasting phase protocol.

<u>Broadcasting Phase Protocol</u>

Rule 1: When M_a receives packet, it treats the destination regions as a large virtual obstacle. The manager M_a makes two copies of the packet, one labeled "*forwarding*" and the other labeled "*around*". Similar to Rule 1 of *reaching phase* protocol, the manager M_a selects three promising managers. Manager M_a sends the "*forwarding*" packet to promising managers located in the destination regions, and sends the "*around*" packet to other promising managers that are not located in the destination region.

Rule 2: If the three promising managers are located in the destination regions, M_a sends the "*around*" packet to the other three neighboring managers to ensure that the "*around*" packet could be transmitted around the destination region. Manager M_a that applies Rule 2 of *Broadcasting Phase Protocol* treats the destination region as a virtual obstacle and applies the Rule 2 and Rule 3 of the *Reaching Phase Protocol*.

Rule 3: A manager M_a that receives the "*around*" packet three times, or a manager that is neither M_d nor M_a will do nothing.

Rule 4: When manager M_d receives the "*forwarding*" packet, it broadcasts to neighbors by flooding.

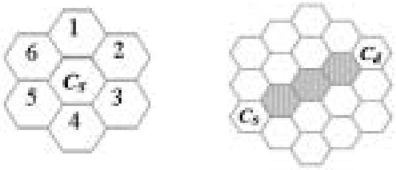
During the execution of broadcasting phase protocol, the packet can be transmitted to all hosts located in the destination regions with a high success rate. Fig. 4 displays the execution of the broadcasting phase protocol.

III. OBSTACLE-FREE MULTI-DESTINATION GEOCASTING PROTOCOL(OFMGP)

This section considers the multi-destination geocasting problem. Assume several disconnected regions exist. The short message will then be delivered from one source host to all hosts located in these regions. If the several disconnected regions are treated as a big destination region, the *reaching* phase protocol and *broadcasting* protocol could be executed to send the short message from one source host to all hosts in this big region. However, this approach creates a large flooding area, causing contention and packet collision. To reduce the size of the flooding area, protocol for solving the multi-destination geocasting problem is proposed herein. The objective of the protocol design is to send short messages to all hosts located in the multi-destination regions, so that packet transmission can overcome unknown obstacles and the size of the flooding area can be controlled.

A. Multi-Destination Geocasting Protocol Without Consideration of Obstacles

This subsection proposes a multi-destination geocasting protocol so that short message packet can be transmitted via a shared path, without considering obstacles. The next subsection discusses the protocol that considers the obstacles. Without considering the obstacles, for any pair of (C_s, C_d), a shortest path for sending packets from C_s to C_d can be found. The C_s cellular is linked to its neighboring cellular regions in six directions. If the cellular C_d is located on one of the six directions of C_s, a unique path can be found. Fig. 5(a) displays the six directions of a cellular. Meanwhile, Fig. 5(b) illustrates that since the C_d is located in direction 2 of C_s, a shortest path for directing the packet from C_s to C_d is easy to construct. However, if C_d is not clearly situated in one of the six directions, several shortest paths from C_s to C_d will exist. As shown in Fig. 6, neither the C_{d1} nor C_{d2} are situated in the six directions of C_s, and thus several path may be constructed for each pair (C_s, C_{d1}) and (C_s, C_{d2}). However, if the packet sent from C_s to C_{d1} and C_{d2} can share same the transmission path, the size of flooding area could be markedly reduced. The present objective is to construct a shared path so that the greatest possible number of destination regions can share the same path. As shown in Fig. 6, some cellular regions are numbered to define the packet transmission flow. The packet can be transmitted over the shared path(or cellular regions), numbered by 1, 2, 3, and 4. The numbered cellular regions are the paths for sending a packet from C_s to destination regions C_{d1} and C_{d2}.



(a) Six transmission directions. (b) Shortest path from *Cs* to *Cd*

Figure 5. Transmission directions and the shortest path.

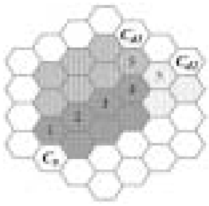


Figure 6. Shared path from C_s to C_{d1} and C_{d2}.

Table I. Relaying Table

Direction	***Destination Region***
1	C_{d2} 、C_{d3}
2	C_{d2} 、C_{d3} 、C_{d4}
3	C_{d4}
4	
5	
6	C_{d1}

To determine the promising managers to which the packet should be transmitted, each manager should maintain a table so that it can quickly check which neighbor has the most potential for relaying the packet to each destination region center C_d. In Table I, the manager records 6 directions. On row i of Table I, if the value of field *Destination Region* is C_d, this denotes that transmitting the packet to the neighboring manager in direction i is the shortest path to destination C_d. For example, in Table I, row 2 has the value C_{d4} meaning that the manager currently relaying the short message packet in direction 2 has a shortest path to destination region C_{d4}.

The following describes the multi-destination geocasting protocol. k central cellulars of the disconnected destination regions are assumed to be C_{di}, $1 \le i \le k$. Managers that receive the "*forwarding*" packet execute the following protocol to determine the receiving neighbors.

<u>Multi-Destination Geocasting Protocol</u>

Step 1: Calculate the distance from six neighboring cellular C_j to all destination regions C_{di}, $1 \le j \le 6$, $1 \le i \le k$. For each destination region center C_{di}, determine the most promising neighboring cellular C_{min} such that distance of (C_{min}, C_{di}) is minimized, where $1 \le min \le 6$. That is,

$$dist(C_{min}, C_{di}) = Min(\ dist(C_j, C_{di})\ ) \text{ for all } 1 \le j \le 6.$$

Record C_{di} on row *min* of Table IV.

Step 2: Select a row (or a direction), say j, $1 \le j \le 6$, with the maximal number of destination regions.

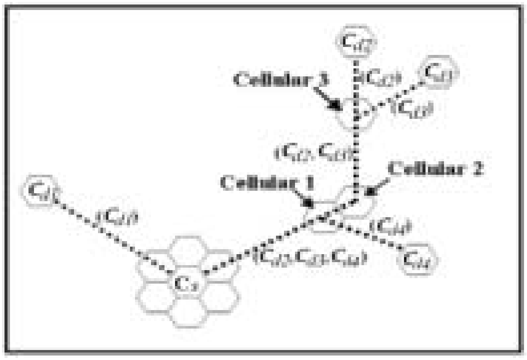
Step 3: If j has a unique value, perform Step 4, and otherwise select the smallest j from the values selected in Step 2.

Step 4: Attach all destination regions C_{di} that belong to row j of relaying table to the packet and transmit the attached packet to the neighbor in direction j.

Step 5: Remove the destination regions C_{di} in Table IV and go to Step 2 until Table IV is Null.

Direction	***Destination Region***
1	C_{d2} 、C_{d3}
2	C_{d2} 、C_{d3} 、C_{d4}
3	C_{d4}
4	
5	
6	C_{d1}

(a) Relaying table of manager located in *C*s.



(b) Shared path construction for multi-destination geocasting.

Figure 7. An example for executing multi-destination geocasting protocol.

The following presents an example for executing the *multi-destination geocasting protocol* mentioned above. Consider the example shown in Fig. 7. The source manager is located in cellular region C_s, and 4 disconnected destination regions exist, whose central regions are C_{d1}, C_{d2}, C_{d3}, and C_{d4} respectively. The dotted line denotes the packet transmission path while the symbol on the dotted line represents the destination information attached to the packet. Applying the proposed *multi-destination geocasting protocol*, the manager of C_s has the relaying table as shown in Fig. 7(a). The source manager thus relays the "*forwarding*" packet to destination regions C_{d2}, C_{d3}, and C_{d4} via direction 2 and relays the "*forwarding*" packet to destination region C_{d1} via direction 6. Once receiving the "*forwarding*" packet, the neighboring managers continuously perform the proposed protocol. As soon as the manager of Cellular1 receives the packet, as shown in Fig. 7(b), it will transmit the packet to destination region C_{d4} via direction 3, and to destination regions C_{d2} and C_{d3} via direction 2. The shared path is constructed until the packet has been delivered to all destination regions. By executing the proposed protocol, the managers of cellular regions C_s, Cellular 1, Cellular 2, and Cellular 3 will create different branches of a shared path so that packet can be delivered to different destination regions.

B. Multi-Destination Geocasting Protocol with Consideration of Obstacles

The previous subsection discussed using shared path construction to reduce the size of the flooding area. This subsection considers the multi-destination geocasting problem in which obstacles are considered. In Fig. 8, the dotted line indicates the packet flow if all managers apply the multi-destination geocasting protocol proposed above. Clearly, the path could be shortened. As soon as the packet is delivered to the manager in location *b*, it can be directly forwarded to location *a*, so that the path length and the transmission time are reduced. Selecting only one direction for sending a packet from the current manager to its neighbor will cause the packet to travel around the obstacle shape. To reduce path length, the following protocol is developed to accelerate packet transmission.

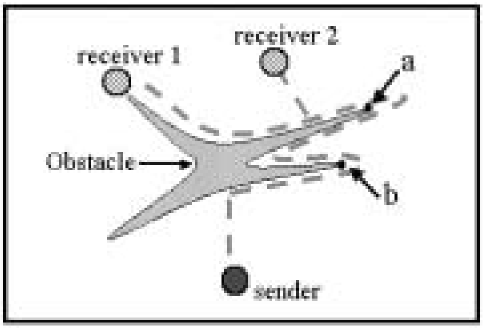


Figure 8. An example of obstacles for multi-destination geocasting problem.

Multi-Destination Geocasting Protocol with Consideration of Obstacles

Rule 1: All managers apply the multi-destination geocasting protocol proposed above, creating a shared path to different destinations.

Rule 2: If the neighboring cell is obstacle, the manager applies the Reaching Phase rules proposed in previous section. That is, for each destination, the manager selects three promising directions for transmitting the packet. If multiple destinations share the same transmitting directions, combine the two packets by putting the destinations together in the packet. Set the packet *Type* by "*Obstacle*".

Fig. 9 presents a running example of the two rules mentioned above. Let *M* denote the manager that currently receives the "*forwarding*" packet. If the neighboring cell contains an obstacle, the manager will analyze the destinations in the packet and select three promising transmission directions for each destination. As shown in Fig. 9, for destination C_{d1}, manager *M* selects directions 1, 5 and 6, while for destination C_{d2}, it selects directions 1, 2 and 6. Finally, manager *M* creates three types of packet with different destinations, C_{d1}, C_{d2}, and C_{d1}+ C_{d2}. These packets, C_{d1}, C_{d2}, C_{d1}+ C_{d2}, are transmitted by manager *M* to its neighbors via directions 5, 2, and 1+6, respectively. By applying the proposed protocol, the managers of MANET create a flooding area, as displayed in Fig. 10. The protocol proposed herein reduces the transmission time, creates a small flooding area, and keep the packet away from the obstacles. The next section implements the proposed protocol to access its performance.

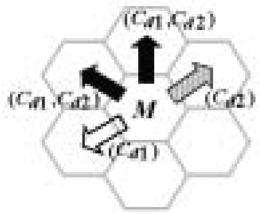


Figure 9. An example for executing the proposed multi-destination geocasting protocol with consideration of obstacles.

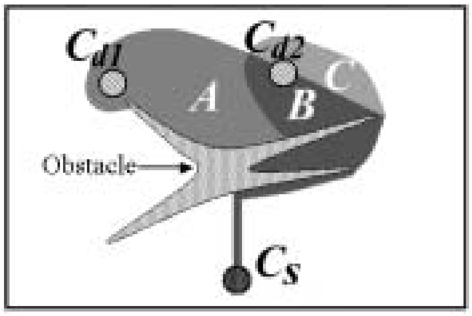


Figure 10. The flooding area of executing the proposed protocol.

IV. PERFORMANCE STUDY

The previous section proposes OFMGP protocol for sending short message from a single source host to multiple geocasting regions. By applying the proposed protocol, the manager of each cellular region transmits the short message packet to create a small and convergent flooding region, reducing bandwidth overheads by transmitting the packet over a shared transmission path, and keeping the packet away from various obstacles. This section proposes the performance investigation of the OFMGP protocol.

The size of the MANET region is 1600*1600 units, while the radio transmission range of a host is set at a constant 100 units. To partition the MANET into several cellular regions, the cellular length is set at $100/\sqrt{3}$. In the MANET environment, the performance of the OFGRP[17] and OFMGP protocols is examined first. Performance measures considered herein include traffic overheads caused by flooding, the success rate in transmitting short message to all hosts in a three disconnected geocasting destinations region, and the time costs in transmitting short message packet to the Multi geocasting region. Besides the performance investigation of multi-destination geocasting, three disconnected geocasting destinations are randomly generated. The number of hosts varies, including 1000, 1250, 1500, 1750, and 2000, and their locations are randomly determined.

In Figs. 11 and 12, three protocols are simulated. First, the multicast flooding protocol floods the short message packet from the source over the whole MANET. The traffic overheads are proportional to the number of hosts, since all hosts participate in the flooding operations. The second protocol, OFGRP, is applied three times to transmit the same short message from the source to different single-destination regions. Compared to OFGRP, the OFMGP has a smaller traffic overhead. This difference occurs because OFMGP analyzes the center locations of each destination region and creates a shared transmission path for the three destination regions.

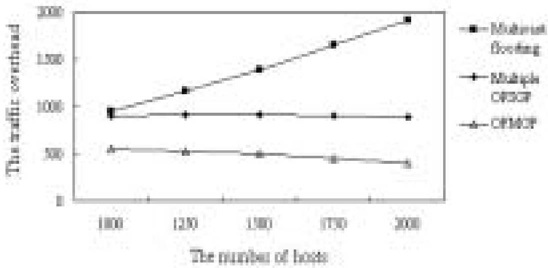


Figure 11. comparison of traffic overhead for multi-destination geocasting protocols.

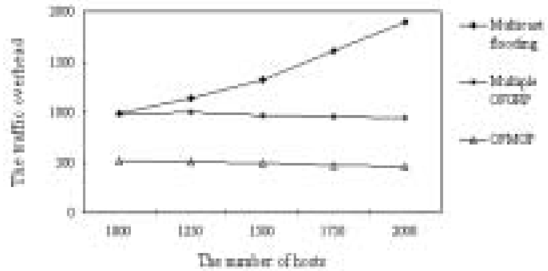


Figure 12. Comparison of traffic overhead for Multi-destination geocasting protocols. The reverse-U-shape and Line-shape geographical obstacles are introduced.

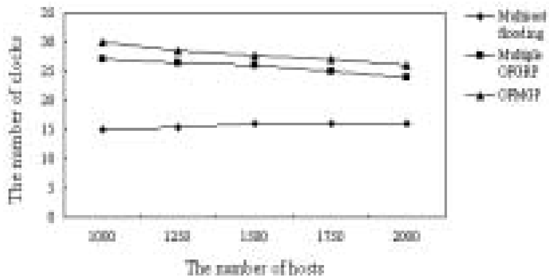


Figure 13. Time cost for Multi-destination geocasting protocols.

Figs. 13 and 14 compare the time costs of the Multicast flooding, OFGRP, and OFMGP protocols. The proposed OFMGP achieves a better performance. As shown in Fig. 13, in case that there is no large obstacle, the time cost for applying OFGRP and OFMGP is very closed. As shown in Fig. 14, in case that there exists a large obstacle, the time cost overhead for OFMGP is larger than OFGRP. This is because that the OFMGP will transmit data to the three most promising directions when the neighboring cell is an obstacle. In general, OFMGP creates a smaller flooding regions and alleviates the bandwidth consumption and packet collision phenomenon for relaying short message from single source to multiple geocasting regions.

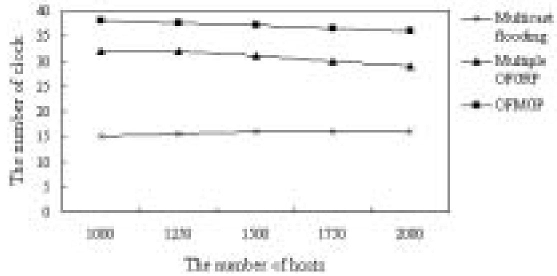


Figure 14. Time cost for Multi-destination geocasting protocols. The reverse-U-shape and Line-shape geographical obstacles are introduced.

V. CONCLUSIONS

This study proposed a novel Multi-destination protocol for the geocasting problem. Compared to existing approaches, the novel protocol creates a shared path for different destinations, so that the number of flooding packets can be reduced as far as possible. The protocols presented herein keep the short-message packet away from the obstacles and create the flooding area in a convergent manner. Simulation results demonstrate that the proposed protocols are obstacle-resistant and performance well in reducing flooding overhead.

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