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Obstacle-Free Geocasting Protocols for Single/Multi-Destination Short Message Services in Ad Hoc Networks

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Abstract. Mobile ad hoc networks (MANET) comprise mobile hosts in a network bereft of base stations and characterized by a highly dynamic network topology. The MANET environment contains unpredictable obstacles, such as mountains, lakes, buildings, or regions without any hosts, impeding or blocking message relay. This study proposes geocasting protocols for sending short message from a source host to single or multiple geocasting regions in ad hoc networks. The proposed protocols keep messages away from unpredictable obstacles and create a small flooding region. Experimental results show that a source host can send a short message to all hosts located in single or multiple geographical areas with a high success rate and low flooding overhead.

Keywords: geocasting, short message, ad hoc network, obstacle, flooding overhead, cellular-based management

1. Introduction

An ad hoc network consisting of mobile hosts provides 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 [14] presented the problem of broadcasting storms and revealed the negative effects of the flooding operation. Various cluster-based protocols [2,4,8,9,15] 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 [5,12] 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 [1], 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 [1].

Different from unicast or multicast service, geocasting service is defined by sending messages from the source to all hosts located in a specific geographical region. Previous works [3,6,7,10,13], assumed that each host is equipped with a GPS that can determine its geographical position. Meanwhile, the source host is capable of defining a specific geocasting region and all hosts located in this region 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 [14]. In [6], Ko proposed a LBM method for solving the geocasting problem. According to the source host location and destination region, a sender defines a forwarding zone and attempts to flood the message in the forwarding zone. If no obstacles exist, the message can be successfully flooded to all host in the destination region. However, if the estimated forwarding zone cannot cover the obstacle, the message will be blocked. In this situation, Ko used a variable δ to enlarge the forwarding zone so that it can cover the obstacle. A large δ value results in a large forwarding zone, thus achieving a high success rate, but also causing contention, collision, and so on. As shown in figure 1, when the variable δ is zero,

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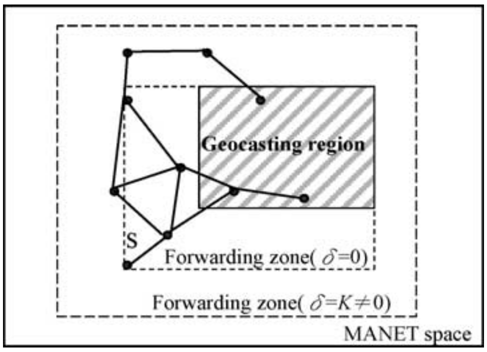


Figure 1. Execution of location-based geocasting protocol.

the forwarding zone does not cover the obstacle. Assuming that the value of variable δ is K, then the forwarding zone can cover all obstacles and the message can be transmitted to the destination region. The performance of geocasting service depends on the value of δ, which is unknown and is defined through trial-and-error. To overcome unpredictable obstacles, setting δ as a large value achieves a high success rate but creates many flooding packets in MANET. In [7,16], a Tora protocol is proposed to construct multiple paths from the source to a specific destination. Although the path constructed by TORA can be automatically recovered, packets are flooded over all MANET regions.

This study focuses mainly on how to deviate from the unpredictable obstacle regions and create a small flooding region so that the message can be successfully relayed from source host to all hosts in the destination region. A OFSGP (Obstacle-Free Single-destination Geocasting Protocol) for MANET is proposed herein, which keeps messages away from obstacles by creating a very small flooding region. Even in cases involving unpredictable obstacles, OFSGP relays the message from the source host to all hosts in a single destination region with a high success rate and low flooding cost. Additionally, 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. Besides OFSGP, OFMGP (Obstacle-Free Multi-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 both single-destination and multi-destination geocasting protocols. Experimental results demonstrate that the proposed protocols transmit the message from source host to one or more destination regions at low cost and with a high success rate.

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

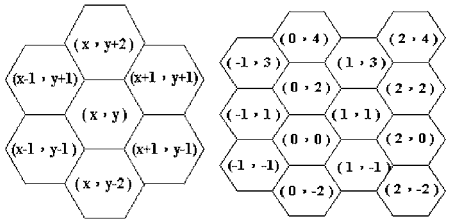


Figure 2. Cellular-ID of a partitioned MANET.

2. Obstacle-Free Single-Destination Geocasting Protocol (OFSGP)

This section illustrates the operation of OFSGP. Examples of executing OFSGP are also described. To reduce the flooding operations, the MANET is assumed to be partitioned. A lot of partitioning schemes [1,11] have been proposed to reduce the flooding overhead so that path can be constructed by executing fewer flooding operations. The partitioning scheme proposed in [1] is adopted herein. The following first introduces the partitioning scheme proposed in [1], and then presents the OFSGP.

2.1. Partitioning of the MANET environment

The obstacle-free geocasting protocol proposed herein is based on the Cellular-Based Management model proposed in [1]. Cellular-Based Management [1] geographically partitions the MANET into several disjoint and equally sized cellular regions, as displayed in figure 2. Each cellular then is assigned a unique Cellular-ID, as shown in figure 2. GPS allows the host to identify which cellular region it is located in, and in each cellular region, the host located closest to the center of the region will be selected as a manager for executing information exchange. The manager of each region is assumed to be capable of communicating directly with the managers of neighboring regions. Each manager will periodically broadcast an "*existence*" message so that the neighboring managers know its existence. If a manager does not receive the "existence" message for a long time, it will mark the neighboring region as an obstacle region and record the information in its table.

The manager of a cellular zone is replaced if the manager enters a new cellular zone. Meanwhile, each host in a cellular should record the ID of that region's manager so that they can relay requests to the manager whenever they need to communicate with other hosts. The manager should periodically broadcast a specific packet to notify members of the region it is located in and notify neighboring manager of its presence. A new manager must be sought if the current manager suffers a fault or suddenly loses power. If a certain time elapses without any MANAGER packet being received, member hosts will repeat the manager selection process. A cellular region without manager is defined as an obstacle region and each manager records the cellular-ID of neighboring obstacle regions.

The geocasting application is defined by sending messages from the source to all hosts located in a specific geographical region. Each host is equipped with a GPS for determining its geographical position. The source host (or sender) can define a specific geocasting region, and all hosts located in this region are considered to be the receivers. Ad hoc networks, contain unpredictable obstacles such as mountains, lakes, buildings, or subregions of MANET which contain no host. These obstacles impede or block message relay. To overcome such obstacles, message flooding from source to the geocasting region is a simple method. However, message spread over MANET is extremely costly and results in serious redundancy, contention, and collision [14]. The next subsection introduces the obstacle-free geocasting protocol that helps the source host to send a short message to all hosts in the destination region by executing few flooding operations and thus overcoming unpredictable obstacles.

2.2. Obstacle-Free Single-Destination Geocasting Protocol (OFSGP)

This subsection presents the Obstacle-Free Single-Destination Geocasting Protocol (OFSGP). The OFSGP mainly consists of two phases, the *reaching phase* and the *broadcasting phase*. 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 reaching phase. 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.

Reaching phase of OFSGP

The OFSGP comprises two phases, the *reaching phase* and the *inner-region-broadcasting phase*. 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 figure 3 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.

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

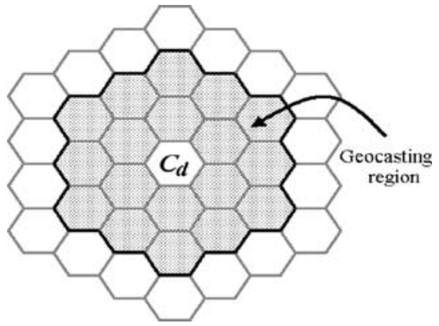


Figure 3. Center location of the geocasting region.

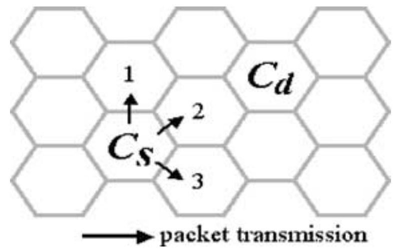


Figure 4. An example of promising cellular regions of C_s.

Dir_i that links the current cellular and the promising cellular is called *promising direction*. Figure 4 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. Examples for executing the Reaching Phase Protocol are provided later.

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 rules*.

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.

The packet format designed for the Reaching Phase Protocol is shown in figure 5. The *Packet ID* represents the ID of short message packet while the *Source Host ID* and *Destination Host ID* respectively denote the ID of the source and destination hosts. Finally, the *Upper Cellular ID* field records the ID of the cell that the packet is transmitted from. This information is used for performing rule 3 since the packet should be returned to the manager that sent the packet to the current manager. The *Type* field records one of the following packet types: "*normal*", "*back*", "*around*" or "*forwarding*". Generally, the packet type is set by a "*normal*" value. As described in rules 2 and 3, provided the current manager can not apply rule 1 to relay the packet to its neighboring managers,

Packet ID
Source Host ID
Destination Cellular ID
Upper Cellular ID
Type
Geocasting Region
Message

Figure 5. Packet format for executing Reaching Phase Protocol.

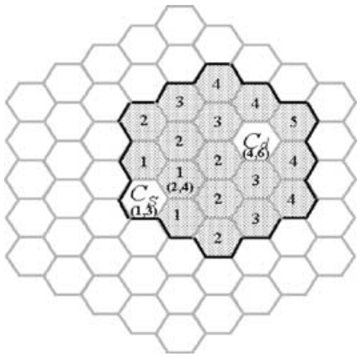


Figure 6. Executing the Reaching Phase Protocol creates a convergent flooding area.

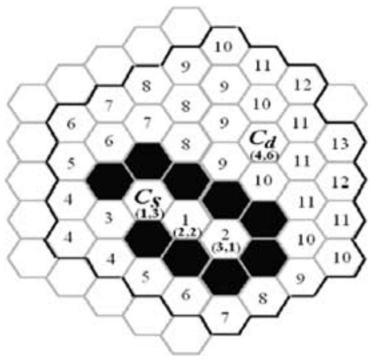


Figure 7. An example for executing reaching phase protocol in obstacle environment.

the packet type will be set by a "*back*" value and returned to the manager of the cellular region indicated by *Upper Cellular ID* field. When a manager receives a "*back*" type packet, it indicates that the packet cannot be relayed to one of the neighboring managers. In case that manager, say X, has received the "*back*" packet from all neighboring managers that previously receive the "*normal*" packet from manager X, manager X treats these neighboring cells as obstacles and applies rule 2 to transmit "*back*" packet to the other neighboring managers. In this case, if all the other neighboring managers are treated as obstacles, rule 2 will be failure and thus manager X applies rule 3. Note that a manager, say Y, that never transmits the "*normal*" packet previously may receive a "*back*" packet. In this case, manager Y creates a "*normal*" packet and applies rule 1 to transmit the "*normal*" packet to the three promising managers. The use of other types of packets, such as "*around*" and "*forwarding*", is illustrated in the following section. The field *Geocasting Region* records the destination region, while the *Message* field carries the contents of short messages. Values of these two fields are given by the source host and will not be changed during protocol execution.

Once receiving a packet, the manager verifies whether or not it is located in the *Destination Cellular ID*. If not, the current manager copies the Upper Cellular ID field of the received packet to its cache, puts its cellular ID in the *Upper Cellular ID* field, then transmits the packet to the promising managers. By executing the reaching phase protocol, the flooding area is automatically convergent. As displayed in figure 6, the shaded regions are the flooding area formed by executing the Reaching Phase Protocol. As the manager of cellular $C_s = (1, 3)$ attempts to send a short message to all hosts located in certain specific regions, it first defines the destination region and sets the related information in the *Geocasting Region* field of the packet. The manager then calculates the coordinate of $C_d = (4, 6)$ and stores this value in the *Destination Cellular ID* field. The other fields of the short message packet are also set by

$$\textit{Source Host ID} = (1, 3),$$
$$\textit{Upper Cellular ID} = C_s = (1, 3), \qquad \textit{Type} = \text{"}\textit{normal}\text{"},$$
$$\textit{Message} = \text{"Dangerous! Get away the square".}$$

Once the packet is created, the manager sends it to its promising neighbors. As the neighboring manager receives the packet, it utilizes the *Upper Cellular ID* and *Destination Cellular ID* to check whether or not it is promising manager. The promising managers will further execute the Reaching Phase Protocol. For example in figure 6, when the manager of cellular (2, 4) receives the packet, it checks the packet contents and knows that the *Upper Cellular ID* = (1, 3) and the *Destination Cellular ID* = (4, 6). According to these information, manager of cellular (2, 4) computes and obtains the promising cellulars (3, 3), (3, 5), and (2, 6). Manager of cellular (2, 4) updates the packet with

$$\textit{Upper Cellular ID} = (2, 4)$$

and then forwards the packet to its promising managers.

The following uses an example to illustrate how the short message can overcome the obstacles by executing the *reaching phase rules*. As shown in figure 7, the black cellular regions denote the obstacles, C_s represents the ID of cellular the sender located, and C_d denotes the central cellular ID of the destination regions. Executing the reaching phase rules creates a flooding region that is surrounded by black lines, as shown in figure 7. The numbers marked in each cellular region denote the packet flows. As the manager of cellular C_s attempts to send a short message to a destination region whose central cellular is C_d, it calculates the promising managers and verifies that cellular (2, 2) is not an obstacle region. The short message packet is then forwarded to the manager of cellular (2, 2). Once receiving the packet, the manager of cellular (2, 2) records the packet information in its cache table, as listed in table 1. The Packet ID field records the packet ID of the received packet. Meanwhile, the *Dir1*, ..., *Dir6* record whether the packet is forwarded to the corresponding direction of the current cellular. For example, in figure 7, the manager of cellular (2, 2) computes that the promising man-

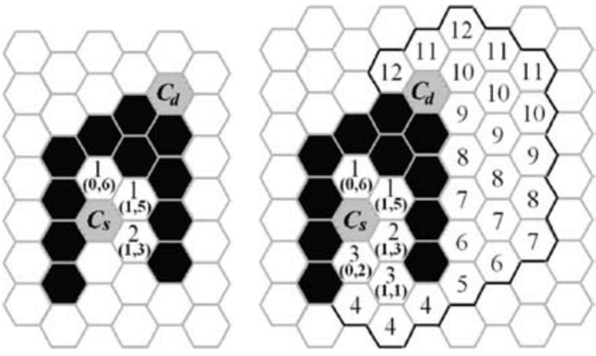
Table 1
The table of information recorded in the manager of cellular (2, 2).

Packet_ID	*Dir1*	*Dir2*	*Dir3*	*Dir4*	*Dir5*	*Dir6*	*Received_From*
A001	F	F	T				(1, 3)
...	...	...	...	...	...	...	...

agers are in directions *Dir1*, *Dir2* and *Dir3*. However, the cellular regions in *Dir1* and *Dir2* are obstacle regions, and the packet can only be sent to the manager of cellular (3, 1). The manager of cellular (2, 2) then sets the *Dir1* and *Dir2* with ‘F’ value, denoting that the packet cannot be sent to its promising managers by these two directions. Since the packet is sent to manager of cellular (3, 1) by direction *Dir3*, the value of *Dir3* in table 1 is set as ‘T’(or “True”). Due to that the packet is received from manager of cellular (1, 3), the *Received_From* field has the value (1, 3). Once receiving the packet, the manager of cellular (3, 1) verifies that the promising regions are obstacles. By applying rule 3 of reaching phase protocol, the manager modifies the *Type* field of packet to “*back*” then returns the packet to (2, 2), the cellular with an ID recorded in the *Received_From* field of its cache table. As soon as manager of cellular (2, 2) receives a “*back*” packet from direction $I(1 \leqslant I \leqslant 6)$, it updates the DIR_i field by value ‘F’. According to the rules of reaching phase, the manager then determines whether or not the received “*back*” packet should be transmitted and which direction the packet should be transmitted. Provided the manager in cellular (2, 2) receives the “*back*” packet, it sets *Dir3* with the value ‘F’. Since all *Dir* fields have the value ‘F’, the manager of cellular (2, 2) applies rule 3 of the reaching phase protocol to return the packet to the manager of cellular (1, 3).

Continuously, by applying rule 2, the manager of cellular (1, 3) sends the packet to the nonpromising cellular regions, and thus the packet is received by manager of cell region 3. The short message thus avoids the obstacles. By applying the reaching phase protocol, the packet can be transmitted to cellular region 10. Since rule 1 indicates that packet will first be sent to the promising managers, the flooding regions will be convergent, as found in cellular regions 10, 11, 12, and 13 in figure 7. By applying the reaching phase protocol, managers can send the short message packet to one host located in the destination region. To avoid the obstacles, the reaching phase protocol creates a small flooding area. According to rule 1, the packet is sent to the promising managers, allowing the flooding area to be convergent. The following subsection describes how the manager calculates the three promising managers based on its six neighboring neighbors.

When the promising cellular regions are obstacles, the current manager applies rule 2 and sends the *“back”* packet to other three neighboring managers, even though the packet received by the current manager is previously sent from one of the three neighboring managers. That is, if the current manager receives the packet from manager M, it should update the *Received_From* field of its table by value ‘M’. When the current manager applies rule 2, then even if M is one of the three nonpromising neighboring managers, the current manager must still send the packet to manager M. This characteristic enhances the obstacle-resistance capability of the packet and helps the short message to overcome obstacles.



(a) (b)

Figure 8. Operation by applying rule 2. (a) Instance of failure. (b) Instance of success.

Table 2
The table of information recorded in the manager of cellular C_s.

Packet_ID	*Dir1*	*Dir2*	*Dir3*	*Dir4*	*Dir5*	*Dir6*	*Received_From*
A001	T	T				F	C_s
...	...	...	...	...	...	...	...

The following uses an example to demonstrate that if the current manager does not send the packet to manager M, the packet may be blocked in the obstacle regions. As shown in figure 8(a), the short message packet is transmitted from source host in C_s to the manager of cellular regions (0, 6) and (1, 5). The source host in C_s will record the packet information as shown in table 2. Since the promising cells (0, 6) and (1, 5) are obstacles, the managers of cells (0, 6) and (1, 5) apply rule 2 to direct the message to the other three neighboring managers. Taking the manager of cell (1, 5) as an example. The manager of C_s is one of the target managers of the manager of cell (1, 5). If the manager of cell (1, 5) does not return the “*back*” packet to the manager of C_s, only the manager of cell (1, 3) receives the “*back*” packet. Hereafter, the manager of cell (1, 3) applies rule 1 to send the packet to the manger of C_s. Oncereceiving the packet sent from the manager of cell (1, 3), the manager of C_s considers this packet as a new packet and resends it to the most promising neighbors, the managers of cells (0, 6) and (1, 5). Consequently, the packet cannot overcome the obstacle regions. The managers of cells (0, 6) and (1, 5) apply rule 2 to return the “*back*” packet to the managers of C_s and (1, 3), as shown in figure 8(b). As soon as the manager of cell C_s receives a “*back*” packet from managers of (0, 6) and (1, 5), it updates the *Dir1* and *Dir2* fields of cache table as shown in table 3. The manager of C_s checks that the most promising directions *Dir1, Dir2,* and *Dir6* fields have value ‘F’, it applies rule 2 and transmits the “*back*” packet to managers of cells (0, 2) and (1, 3). The packet can finally be transferred to the managers of cells (1, 1) and (0, 2). By continuously applying the three rules in the proposed protocol, the packet can overcome obstacles, even though the obstacles are difficult to overcome.

Table 3
The table of information recorded in the manager of cellular C_S.

Packet_ID	*Dir1*	*Dir2*	*Dir3*	*Dir4*	*Dir5*	*Dir6*	*Received_From*
A001	F	F				F	C_S
...	...	...	...	...	...	...	...

Section 5 discusses the success rate for special obstacles, such as the reverse-U-shape and Line-shape obstacles.

In the following, a Reaching Phase Protocol is proposed to implement the three rules described before. On receiving a packet P from direction Dir_j, manager M executes the following Reaching Phase Protocol.

The Reaching Phase Protocol.

Step 1. This step implements rule 1 proposed before. On receiving a "*normal*" or "*back*" packet P from the neighboring manager, the cell manager M checks whether or not it has transmitted the packet. If manager M has transmitted this packet before, it executes steps 2 or 3, otherwise, it creates and transmits a "*normal"* packet to the promising managers, sets the promising directions Dir_i with 'T' value in its table, and changes its state to "*promising*", denoting that the promising directions are feasible for relaying the short message to the geocasting region.

Step 2. This step implements rule 2 proposed before. Manager M executes this step if it is in "*promising*" state. If the "type" of the packet P is "*back*", manager M updates the corresponding Dir_j field by value 'F' in its table. Manager then checks the direction fields of its table.

(1) If any promising direction has 'T' value, manager M will do nothing for this packet. The reason is from the fact that at least one "*normal*" packet transmitted from the manager M has opportunity to reach the geocasting region.

(2) If all promising directions have 'F' value, manager M creates and transmits a "*back*" packet to the non-promising managers. Manager M then sets the non-promising directions with 'T' value in its table and changes its state to "*non-promising*", denoting that the non-promising directions are feasible for relaying the short message to the geocasting region.

Step 3. This step implements rule 3 proposed before. Manager M executes this step if it is in "*non-promising*" state. If the type of the packet P is "*back*", manager M updates the corresponding Dir_j field by value 'F' in its table. Manager then checks the direction fields of its table.

(1) If any non-promising direction has 'T' value, manager M will do nothing for this packet. The reason is from the fact that at least one "*back*" packet transmitted from manager M has opportunity to reach the geocasting region.

(2) If all the promising directions have 'F' value, manager M creates and transmits a "*back*" packet to the manager that is recorded by the *Received_From* field in its table. Consider the case that manager M originally receives a "*normal*" packet from manager M' who is a promising manager of M. In this case, applying step 2 will cause that M' can not receive the "*back*" packet, since step 2 only sends the "*back*" packet to the non-promising managers. Step 3 guarantees that manager M' can receive a "*back*" packet from manager M in this case.

Step 4. Manager M will do nothing if it applies steps 1, 2, and 3 but can not transmit packet to any one of the neighboring manager. A manager M executes step 4 if it is located in a region whose neighboring regions are surrounded with obstacles.

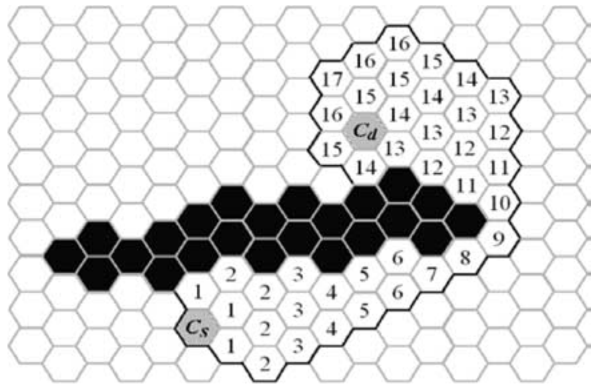


Figure 9. Special case of Line-shape obstacles.

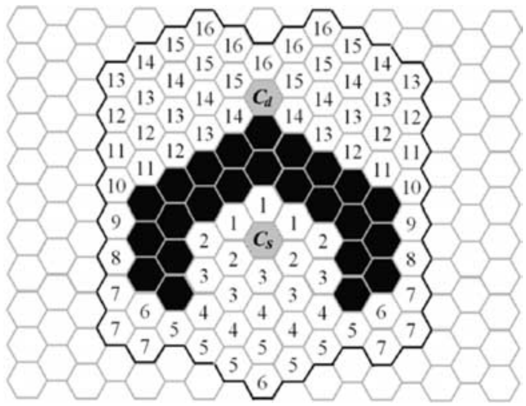


Figure 10. Special case of reverse-U-shape obstacles.

Examples of obstacles

This subsection uses two special cases to demonstrate that the reaching phase protocol can successfully send the packet to the destination regions and overcome the obstacles by creating a small flooding area. In figures 9 and 10, the black cellular regions represent the obstacles, each flooded region is numbered according to the order of packet flow. As displayed in figure 9, the short message transmitted from C_s to C_d is impeded by Line-shape obstacle. Applying the Reaching Phase Protocol, allows the packet to be transmitted in a very small flooding area, so that it can overcome the obstacle and finally reach the destination region. Meanwhile, the LBM Geocasting Protocol [6] creates a larger flooding area than the novel protocol, as shown in figure 11. Another case is when the C_s surrounded by obstacles, as shown in figure 10. Short message packet also can be transmitted from C_s to the geocasting region. Additionally, the flooding area can be convergent within a very small area, depending on the shape of obstacle.

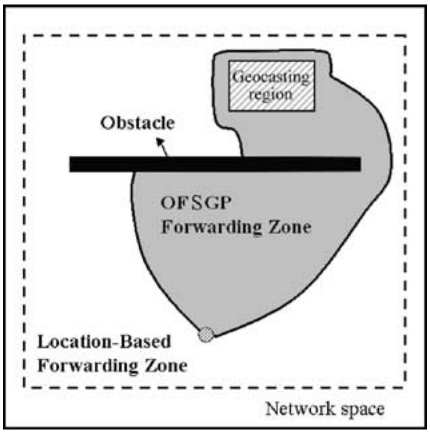


Figure 11. Comparison of flooding area of OFSGP and LBM protocols.

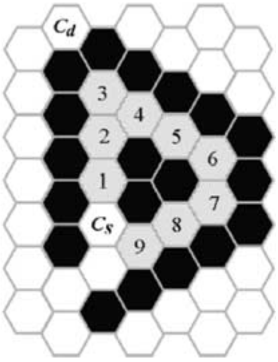


Figure 12. Loop problem that blocks the packet transmission.

The efficiency of the novel protocol and previous approaches is shown in section 4.

Loop problem and its solution

Although the proposed protocol has a high success rate in transmitting the short-message packet, some types of obstacle will cause packet transmission to enter a loop and thus fail to reach the destination region. For example, consider the obstacle shown in figure 12. The black cells are obstacles, and some cells are numbered to denote the order of packet flow. The source host located in cell C_s transmits the packet to the three promising managers, where two of the managers are obstacles and one is located in cell number one. By applying the proposed protocol, the packet will be flooded in an order according to the indicated number on cell. As soon as the packet is flooded to cell number 9, manager of this cell transmits the packet to the manager of C_s, which is one of the three promising managers of cell 9. Since the manager of C_s has already transmitted this packet, it will not retransmit it thus blocking the packet among the obstacles.

For solving the loop problem, managers of cells close to the obstacles can record obstacle information and exchange this information with neighbors so that managers can determine the shape of obstacle. Provided the packet has been received by these managers, they can make a good decision regarding whether or not the received packet should be retransmitted (in a loop condition). Consequently, the probability of packet transmission failure in geocasting applications is reduced.

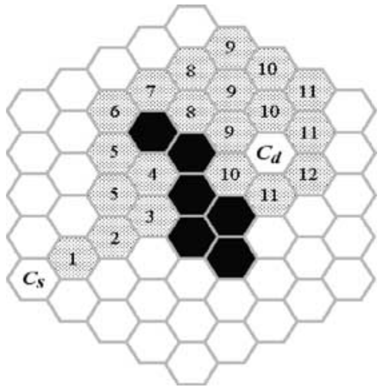


Figure 13. Execution of EOFRP.

Enhanced Obstacle-Free Reaching Phase Protocol (EOFRP)

This subsection proposes an enhanced Obstacle-Free Reaching Phase Protocol. The protocol proposed in this subsection reduces the size of flooding area before the presence of any obstacle. Rather than selecting the three promising managers, the current manager selects just one promising manager to which it then relays the packet. This approach reduces the size of the flooding area, as no obstacle exist in MANET. As soon as obstacles are encountered, manager applies the previously proposed Reaching Phase Protocol, which selects three promising managers for overcoming the obstacles. Figure 13 displays the operations of the Enhanced Reaching Phase Protocol.

To keep away from the obstacles, the short message is flooded in a small region to ensure the message can be sent to a single host located in the destination region. During the reaching phase, the size of the flooding region is dynamically convergent, according to the shape of the obstacles. As soon as the packet can be delivered to a manager in the destination regions, managers perform the second phase protocol so that the packet can be transmitted to all managers in the destination regions.

Broadcasting phase of OFSGP

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

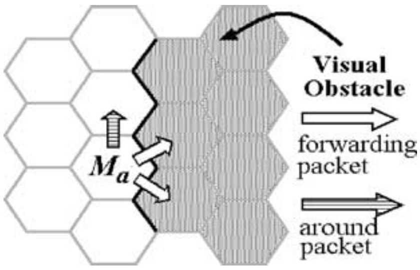


Figure 14. Operation of Broadcasting Phase Protocol.

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*.

Broadcasting Phase Protocol.

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, manager that is neither M_a nor M_d will do nothing. Figure 14 illustrates the operation of the broadcasting phase protocol, where the black cells are destination regions. When the around manager M_a receives packet, it checks that itself is an *around manager* and prepares two types of packets, as illustrated by rule 1 and rule 2. Manager M_a treats the whole destination regions as a virtual obstacle, evaluates the three promising managers, and sends packets to cellular regions indicated by an arrow. Two of the promising managers are located within the destination regions and will receive the "*forwarding*" packet from M_a. Meanwhile, one of the promising managers which is located close to the destination regions, will receive the "*around*" packet from M_a.

Once the "*forwarding*" packet has been delivered to the destination regions, managers that are located in the destination regions will receive the "*forwarding*" packet and broadcast the packet to all hosts in destination regions. However,

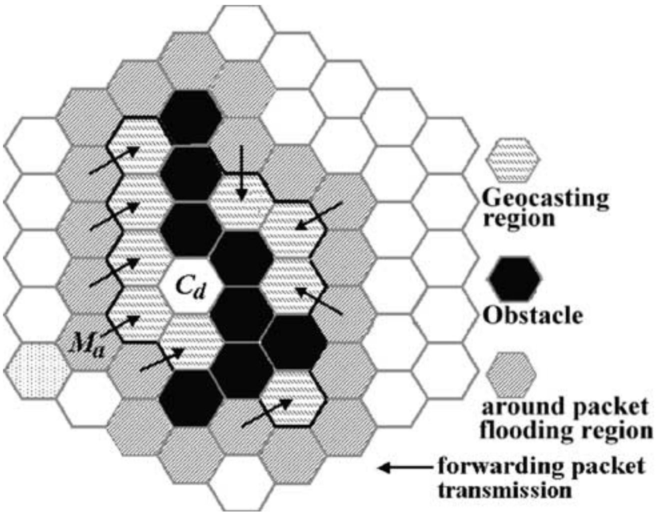


Figure 15. Operation of Broadcasting Phase Protocol.

obstacles may exist in the destination region that blocks the packet transmission. Figure 15 is a special case that blocks the flooding operation. To ensure that all hosts in the destination regions will successfully receive the packet, the proposed Broadcasting Phase Protocol uses the "*around*" packet to increase the opportunities for transmitting the packet into the blocked regions. The *around manager* M_a treats the destination regions as a virtual obstacle and applies the rule 1 and rule 2 of broadcasting phase so that the "*around*" packet can be transmitted along the destination regions. Consequently, the packet can be transmitted to all hosts located in the destination regions with a high success rate. Figure 15 displays the execution of the Broadcasting Phase Protocol.

3. 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.

3.1. Multi-Destination Geocasting Protocol without considering 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.

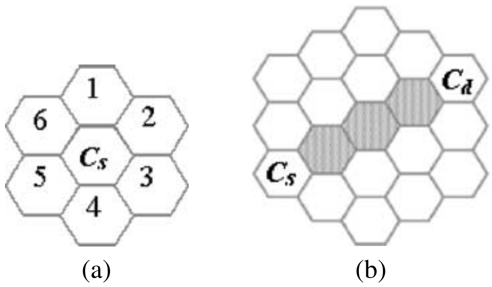


Figure 16. Transmission directions and the shortest path. (a) Six transmission directions. (b) Shortest path from C_s to C_d.

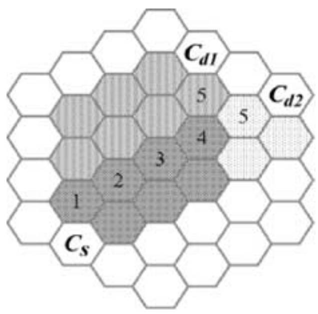


Figure 17. Shared path from C_s to C_{d1} and C_{d2}.

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. Figure 16(a) displays the six directions of a cellular. Meanwhile, figure 16(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 figure 17, 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 figure 17, 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}. 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.

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 4, the manager records 6 directions. On row i of table 4, 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 4, 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}.

Table 4
Relaying table

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

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

Multi-Destination Geocasting Protocol.

Step 1. Calculate the distance from six neighboring cellular C_j to all destination regions C_{di}, $1 \leqslant j \leqslant 6$, $1 \leqslant i \leqslant k$. 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 $1 \leqslant min \leqslant 6$. That is,

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

Record C_{di} on row *min* of table 4.

Step 2. Select a row (or a direction), say j, $1 \leqslant j \leqslant 6$, 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.

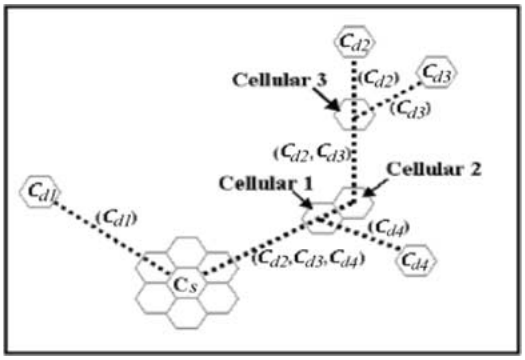
Step 4 Attach all destination regions C_{di} that belong to row j of relaying table to the packet and transmit the attached packet to the neighbor in direction j.

Step 5. Remove the destination regions C_{di} in table 4 and go to step 2 until table 4 is Null.

The following presents an example for executing the Multi-Destination Geocasting Protocol mentioned above. Consider the example shown in figure 18. 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 figure 18(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 Cellular 1 receives the packet, as shown in figure 18(b), it will transmit the packet to destination region C_{d4} via direction 3, and to destination regions C_{d2} and

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

(a)



(b)

Figure 18. An example for executing Multi-Destination Geocasting Protocol. (a) Relaying table of manager located in C_s. (b) Shared path construction for multi-destination geocasting.

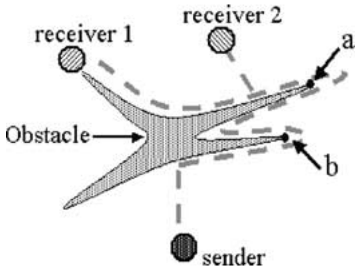


Figure 19. An example of obstacles for multi-destination geocasting problem.

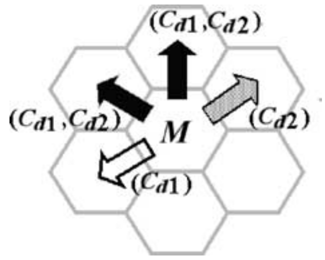


Figure 20. An example for executing the proposed Multi-Destination Geocasting Protocol with consideration of obstacles.

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.

3.2. 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 figure 19, 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 accelerte packet transmission.

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 Protocol of OFSGP. 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 packet by putting the destinations together in the packet. Set the packet type by "*Obstacle*".

Figure 20 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 figure 20, 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 figure 21. 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.

4. Performance study

The previous section respectively proposed OFSGP and OFMGP protocols for sending short message from a single

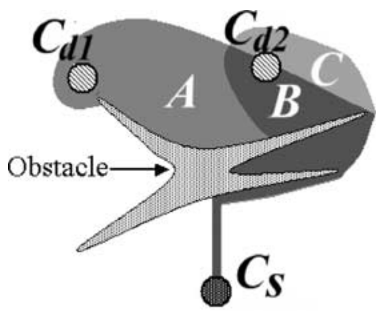


Figure 21. The flooding area of executing the proposed protocol.

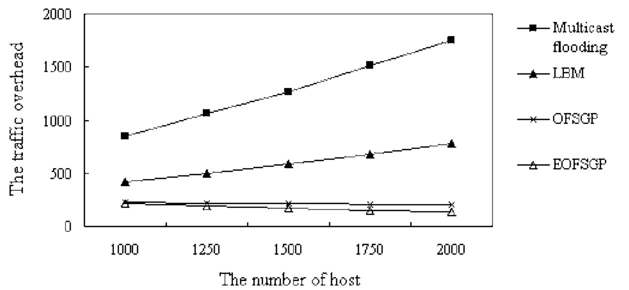


Figure 22. Comparison of traffic overhead for single-destination geocasting protocols.

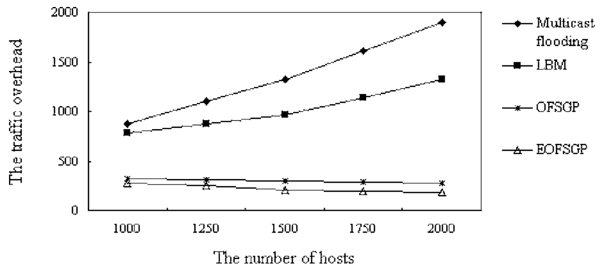


Figure 23. Comparison of traffic overhead for single-destination geocasting protocols. The reverse-U-shape and line-shape geographical obstacles are introduced.

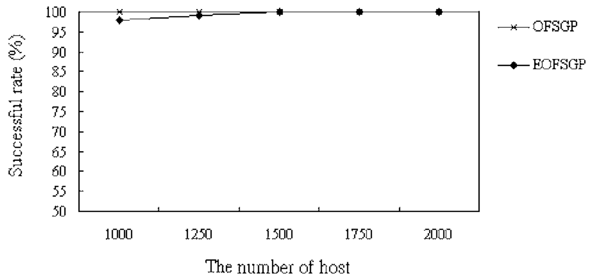


Figure 24. Comparison of successful rate for single-destination geocasting protocols. The obstacles are randomly generated.

source host to single and multiple geocasting regions, respectively. 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 OFSGP and the OFMGP protocols.

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 LBM [6], OFSGP, EOFSGP protocols is examined first. The EOFSGP protocol is the same as the OFSGP protocol, except that the Enhanced Reaching Phase Protocol is adopted rather than Reaching Phase Protocol of OFSGP. Performance measures considered herein include traffic overheads caused by flooding, the success rate in transmitting short message to all hosts in a single geocasting region, and the time costs in transmitting short message packet to the single geocasting region. The number of hosts varies, including 1000, 1250, 1500, 1750, and 2000, and their locations are randomly determined. The δ value of LBM is set at 50 units.

Figure 22 compares the traffic overheads of the LBM, OFSGP, EOFSGP and Multicast Flooding protocols. Using the Multicast Flooding and LBM protocols, each host transmits the short message packet hop by hop until the packet has been delivered to the geocasting region. Thus, the traffic overhead is proportional to the number of hosts. However, in the proposed OFSGP and EOFSGP models, the MANET is partitioned into a fixed-size cellular region and only the managers of each region participate the packet transmission. Traffic overheads thus do not increase with the number of hosts. The number of cellular regions without managers decreases with an increasing number of hosts, thus decreasing the number of obstacles. Consequently, the traffic overheads involved in keeping the short message away from the obstacles are saved. If the neighboring region is not an obstacle, managers that apply the EOFSGP protocol only transmits packet to the most promising manager, instead of transmitting packet to the three neighboring managers. An increasing number of hosts means fewer cellular regions contain obstacles and thus reduce the traffic overheads for transmitting a packet to three neighboring managers. This phenomenon is significant as found in EOFSGP.

To examine the effect of the loop problem caused by natural obstacles, such as mountains, lakes, rivers, and valleys in the MANET environment, the reverse-U-shape and line-shape geographical obstacles are randomly generated herein. As shown in figure 23, traffic overheads are increased significantly in the LBM protocol. This phenomenon occurs because that the value of δ is too small to allow the flooding region to cover the obstacles. Trial and error testing with a larger δ value expands the flooding region and thus increases traffic overheads. When the OFSGP and EOFSGP protocols are applied, some additional managers participate the packet transmitting operations, allowing the packet to be kept away from the obstacles. However, the traffic overheads do not significantly affect the proposed protocols. Section 2.2 discussed the loop problem, which can cause the packet failure in getting away from reverse-U-shape obstacles. Applying the proposed OFSGP and EOFSGP protocols may result in failure when sending short message to all of the hosts located in the geocasting destination region. Figures 24 and 25 display the

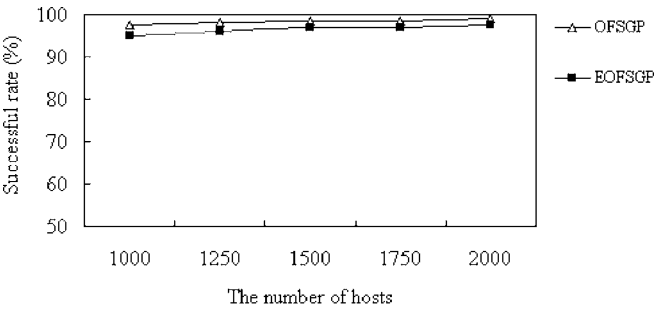


Figure 25. Comparison of successful rate for single-destination geocasting protocols. The reverse-U-shape and line-shape geographical obstacles are introduced.

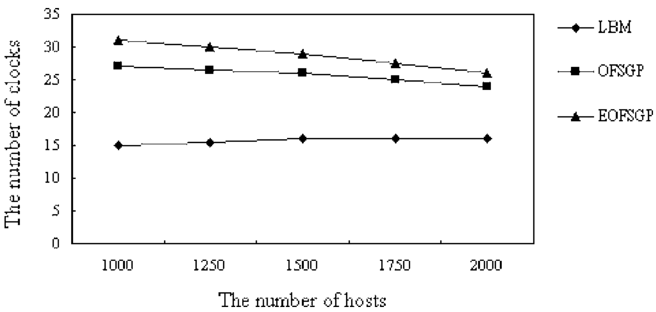


Figure 26. Time cost for single-destination geocasting protocols.

success rate of OFSGP and EOFSGP. In figure 24, the obstacles are randomly generated, and since most of the obstacles are small blocks and do not cause the loop problem, the success rate of the two proposed protocols is high. However, figure 25 shows that the success rate decreases when reverse-U-shape obstacles are randomly generated.

Figures 26 and 27 compare the time costs of the LBM, OFSGP, and EOFSGP protocols. Notably, in figure 26, obstacles are formed because some cellular regions lack a host. Since the obstacles are mostly small blocks, the LBM uses a flooding based mechanism to transmit packets, and thus achieves a smaller time cost than OFSGP and EOFSGP. Figure 27 displays randomly generated the reverse-U-shape and Line-shape obstacles on MANET. Compared with figure 26, the time costs of LBM are increased significantly in figure 27. Since the initial δ value of LBM can not cover the geographical obstacles, a second flooding from source to destination region is the key reason for the increasing time cost.

Besides the performance investigation of single-destination geocasting, three disconnected geocasting destinations are randomly generated. As shown in figure 28, 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, OFSGP, is applied to transmit the same short message three times from the source to different single-destination regions. Compared to OFSGP, the OFMGP has a smaller traffic overhead than the multicast flooding and OFSGP protocols. This difference occurs because OFMGP

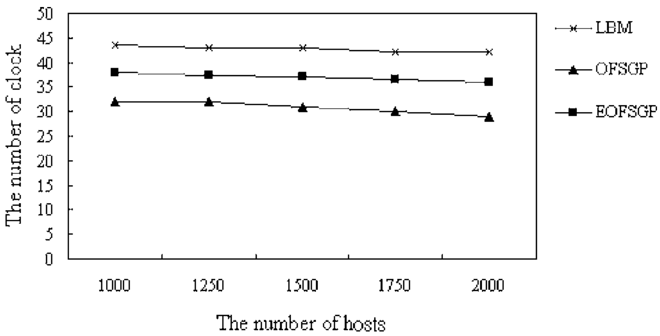


Figure 27. Comparison of traffic overhead for multi-destination geocasting protocols.

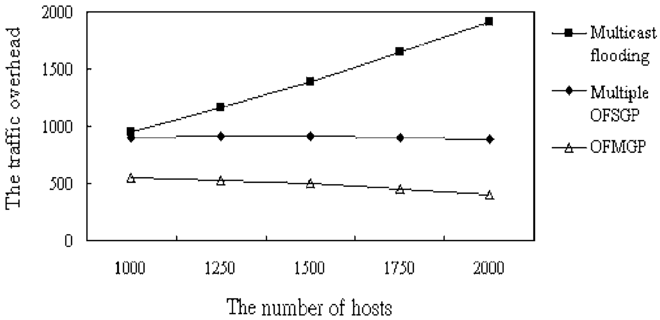


Figure 28. Time cost for single-destination geocasting protocols. The reverse-U-shape and line-shape geographical obstacles are introduced.

analyzes the center locations of each destination region and creates a shared transmission path for the three destination regions.

5. Conclusions

This study proposed a novel single-destination protocol for the geocasting problem. Compared to existing approaches, the novel protocol creates a smaller flooding area and achieves a higher success rate for relaying a packet to a single-destination geocasting region. For multi-destination geocasting problem, protocol to create a shared path for different destinations is proposed, 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 terms of success rate and flooding overheads.

Acknowledgements

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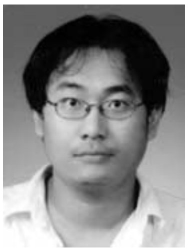

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