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Flooding-Based Geocasting Protocols for Mobile Ad Hoc Networks

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Abstract. Geocasting is a variation on the notion of multicasting. A geographical area is associated with each geocast, and the geocast is delivered to the nodes within the specified geographical area. Thus, geocasting may be used for sending a message that is likely to be of interest to everyone in a specified area. In this paper, we propose three geocasting protocols for ad hoc networks, obtained as variations of a multicast flooding algorithm, and then evaluate these approaches by means of simulations. Proposed geocasting algorithms attempt to utilize physical location information to decrease the overhead of geocast delivery.

Keywords: geocasting, flooding, mobile ad hoc networks, GPS

1. Introduction

Mobile ad hoc networks consist of wireless mobile hosts that communicate with each other, in the absence of a fixed infrastructure [1]. Routes between two hosts in a Mobile Ad hoc NETwork (MANET) may consist of hops through other hosts in the network. The ability to establish an ad hoc network without using a fixed infrastructure makes them useful in many scenarios, including disaster recovery, search-and-rescue in remote areas, and home networking applications.

When an application must send the same information to more than one destination, multicasting is often used, because it is more efficient than multiple unicasts in terms of the communication costs. Cost considerations are all the more important for a MANET because the mobile hosts communicate with each other over wireless links [1]. In MANET environments, the multicast problem is complex because network topology change may be frequent.

To do multicasting, some way is needed to define multicast groups. In conventional multicasting algorithms, a multicast group is considered to be a collection of hosts which register to that group. Thus, if a host wants to receive a multicast message, it must join the appropriate multicast group first. When a host sends a message to such a multicast group, all group members receive the message.

In this paper, we consider a variation of multicasting, namely, *geocasting*. Geocasting is useful for sending a message that is likely to be of interest to everyone in a specified area. Thus, a geocast is delivered to the set of nodes within the specified geographical area. Unlike the traditional multicast schemes, here, *geocast group* is implicitly defined as the set of nodes within the specified area. We will refer to the specified area as the "geocast region" – set of nodes in the geocast region forms the geocast group. If a host resides within the geocast region at a given time, it automatically becomes a member of the corresponding geocast group at that time. To determine group membership, each node is required to know its own physical location, i.e., its precise geographic coordinates, which may be obtained using the Global Positioning System (GPS) [9].

This paper proposes three geocasting protocols for mobile ad hoc networks, obtained as variations of a multicast flooding algorithm. Proposed algorithms attempt to utilize physical location information to decrease the overhead of geocast delivery.

Rest of this paper is organized as follows. The next section discusses some related work. Sections 3 and 4 describe preliminaries and proposed geocasting approaches for MANET. Simulation results for our algorithms are presented in section 5. Finally, section 6 presents conclusions.

2. Related work

The notion of geocasting was proposed by Navas and Imielinski [11,17] in the context of the Internet. In their scheme also, group members are (implicitly) defined as all nodes within a certain region. To support location-dependent services such as geographically-targeted advertising, they suggested three methods: Geographic Routing Method (i.e., georouting with location aware routers), Geographic Multicast Routing Method (i.e., geo-multicasting modifying IP multicast), and Domain Name Service Method (i.e., an application layer solution using extended domain name service). Although their work is mainly focused on the Geographic Routing Method, geographically directed multicast is also proposed to leverage the power of multicast when delivering the geographic messages to their multicast destinations. It is important to note that, while the work by Navas et al. is on geocasting in the Internet, this paper considers geocasting in mobile ad hoc networks.

Several protocols for multicasting in mobile ad hoc environments have been proposed based on a tree-based approach [4,12,19,22]. Ad hoc Multicast Routing (AM-Route) protocol [4] creates a bidirectional shared multicast tree using explicit group joining and tree construction messages to provide connections between multicast group members. With the Ad hoc Multicast Routing protocol utilizing Increasing id-numberS (AMRIS) algorithms [22], a shared delivery tree rooted at a special node is also constructed and maintained for the multicast group. A newly extended version of AODV (Ad hoc On-demand Distance Vector) for providing the multicast operation of ad hoc networks may be categorized as a tree-based approach as well [19].

Using a multicast mesh structure for ad hoc multicasting protocols has also been proposed to improve reliability and to overcome the limitations of multicast trees, such as frequent tree reconfiguration and connectivity changes [7,15,16,20]. For instance, On-Demand Multicast Routing Protocol (ODMRP) [15] uses a mesh of nodes for multicast data delivery. ODMRP has been further extended to make it adaptive to host mobility by using location and mobility information provided by the GPS [16].

Recently, arguing that conventional tree-based approaches are not appropriate for multicasting in ad hoc networks, Obraczka et al. [8,18] have suggested the use of flooding as a viable alternative. They point out that flooding is attractive for highly dynamic ad hoc environments because it does not need to maintain as much network state as the tree-based protocols.

The algorithms proposed in this paper are based upon the multicast flooding approach, and the basic idea is derived from the Location-Aided Routing (LAR) protocols proposed for unicast routing in MANET [13,14]. The closest work to ours was recently presented in [3]. They have presented a geographic message dissemination mechanism for building a position database and showed the performance of their dissemination method by applying it to a geographically aware application named "geographic messaging" which is analogous to geocasting. Our work also considers using location information to improve performance of geocasting data delivery. However, our work here differs from [3] in that our geocasting protocols do not need any extra control packet overhead. Note that, in [3], each node periodically broadcasts its position information in control packets throughout the network to maintain a location database that is utilized for delivery of geographic messaging.

3. Preliminaries

3.1. Physical location information

With the fast-growing use of GPS equipment, mobile users can more easily determine where they are located [9]. The GPS receivers allow users to obtain their physical location information such as three-dimensional position (latitude, longitude, and altitude),[1] velocity, and precise time traceable to Coordinated Universal Time (UTC) [21].

In reality, position information provided by GPS includes some inaccuracy, i.e., some amount of *error* which is the difference between GPS-calculated coordinates and the real coordinates. This GPS error is mainly dependent on both physical errors and artificial errors such as the selective availability (SA). SA was intentionally introduced by the DoD for national security reasons, giving the military a far more accurate system than civilians. Based on the degree of accuracy, two positioning services were available: Standard Positioning Service (SPS) that provides civilian users a 100 m accuracy, and Precise Positioning Service (PPS) providing 20 m accuracy to military users [21]. Recently, DoD has decided to turn off the SA, allowing civilian users to get as accurate location infromation as the military does. This can be a very significant step forward in furthering the utility of GPS for commercial use. In our discussion here, we assume that each host knows its current location *precisely* (i.e., no error). However, our algorithms can be easily extended to take location error into account, similar to the routing algorithms in [14].

3.2. Geocast flooding

Flooding is probably the simplest approach to implement multicasting [10]. The flooding algorithm can also be used to deliver packets to hosts within a geocast region. Figure 1 illustrates the simple geocast flooding algorithm with an example network.[2] Assume that a host S needs to send a geocast to the geocast region depicted by a circle. Initially, the source S broadcasts the geocast packet to all its neighbors.[3] A description of the geocast region is included in each geocast packet. In figure 1, since the "dark" hosts D, F and G are present in the specified geocast region, they belong to the corresponding geocast group. A host, say Z, on receiving the packet, compares the geocast region's coordinates with its own location. If host Z is within the geocast region, it will accept the packet. Also, Z will propagate the packet to its neighbors, if it has not received the packet previously (repeated reception of a packet is detected using sequence numbers). If host Z is located outside the geocast region, and the packet was not received previously, it just broadcasts the packet to its neighbors. Note that with the geocast flooding protocol, all hosts reachable from the source S will receive the geocast message.

3.3. Forwarding zone

Forwarding zone defined here for geocasting is similar to that defined for unicast routing in [14]. As an illustration, let us consider a rectangular geocast region, as shown in figure 2. Assume that node S geocasts a data packet at time t_0, and three nodes (X, Y, and Z in figure 2) are located within the

[1] In this paper, we assume that the mobile nodes are moving in a two-dimensional plane.

[2] Arrows in the figure denote transmissions of the geocast packet.

[3] Two hosts are said to be *neighbors* if they can communicate with each other over a wireless link.

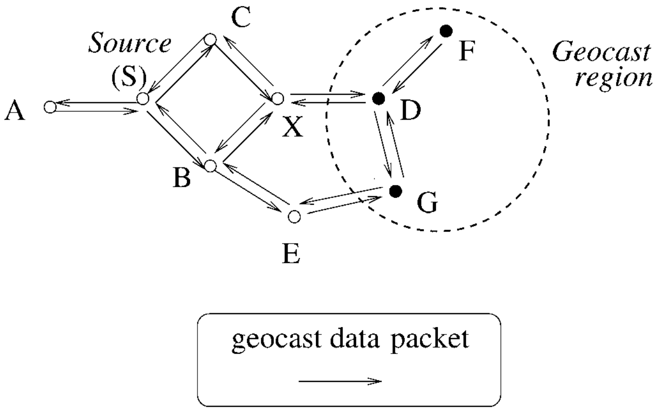


Figure 1. Illustration of *geocast flooding* algorithm.

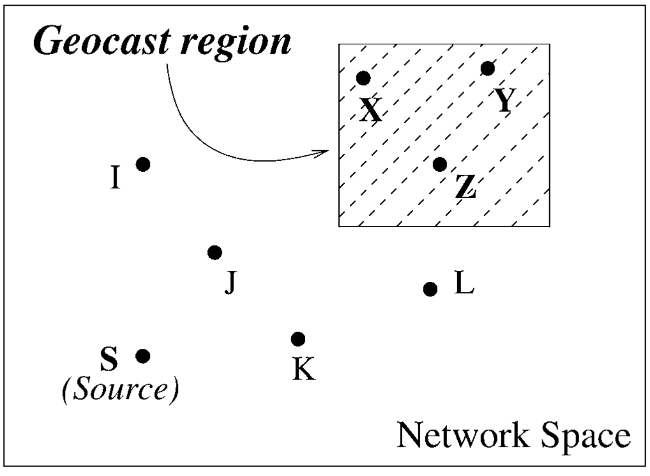


Figure 2. Geocast region and geocast group.

geocast region at that time, forming the geocast group at time t_0. Recall that a node automatically becomes a member of the geocast group when it moves into the geocast region, and leaves the group when it moves out of the geocast region.

The proposed geocasting algorithms basically use geocast flooding with one modification. A source node S defines (implicitly or explicitly) a "forwarding zone" for a geocast data packet. A node forwards the geocast packet *only if* it belongs to the forwarding zone (unlike the geocast flooding algorithm).

With the use of a forwarding zone as described above, geocast packets are forwarded by a smaller set of nodes, as compared to geocast flooding. To increase the probability that a data packet will reach all members in the geocast group, the forwarding zone may include, in addition to the geocast region itself, other areas around the geocast region. When the geocast region does not include the source node S, a path from S to geocast group members may include nodes outside the geocast region. Therefore, additional region should be included in the forwarding zone, so that node S and nodes in the geocast region both belong to the forwarding zone (for instance, as shown in figure 3(a)[4]).

[4] In the figure, an edge between two nodes means that they are neighbors.

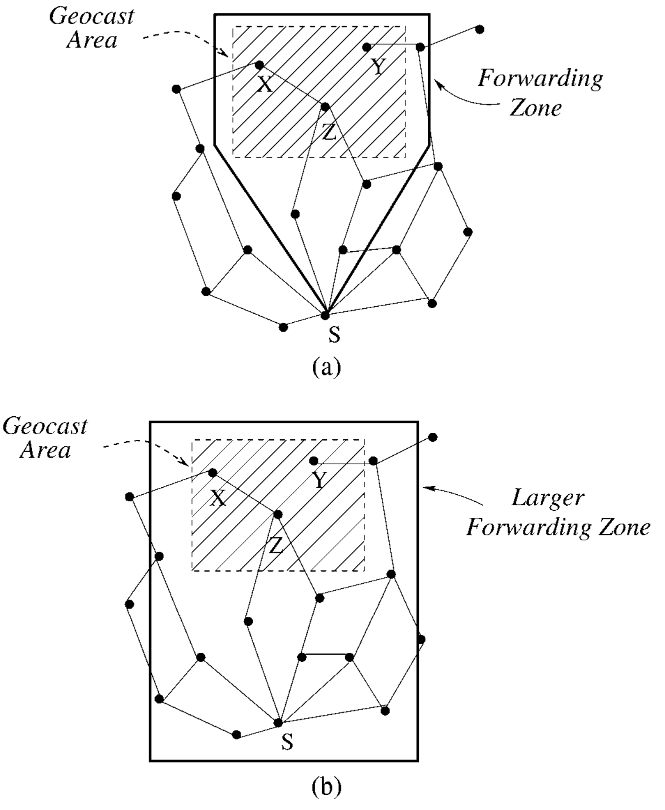


Figure 3. Definition of forwarding zone.

To be a useful geocast protocol, it is necessary to achieve a high probablity that a geocast is delivered to each geocast member (we later formally define this as the *accuracy* of a geocast protocol). Note that accuracy of the protocol can be increased by increasing the size of the forwarding zone. For instance, in figure 3(b), a geocast packet can reach node Y, unlike in figure 3(a). However, data delivery overhead may also increase with the size of the forwarding zone. Thus, there exists a tradeoff between accuracy of geocast delivery and the overhead of geocast delivery.

4. Proposed geocasting protocols

In this section, we describe the proposed geocasting algorithms using physical location information of mobile nodes. Essentially, the proposed geocasting protocols are identical to geocast flooding, with the modification that a node which is not in the forwarding zone does not forward a geocast packet to its neighbors. The three protocols proposed here differ in the way the forwarding zone is defined.

4.1. Static zone scheme

Our first scheme uses a forwarding zone that is rectangular in shape (refer to figure 4). The forwarding zone is defined to be the smallest rectangle that includes current location of source S and the geocast region, such that the sides of the rectangle are parallel to the X (horizontal) and Y (vertical) axes. In figure 4(a), the geocast region is the rectangle whose cor-

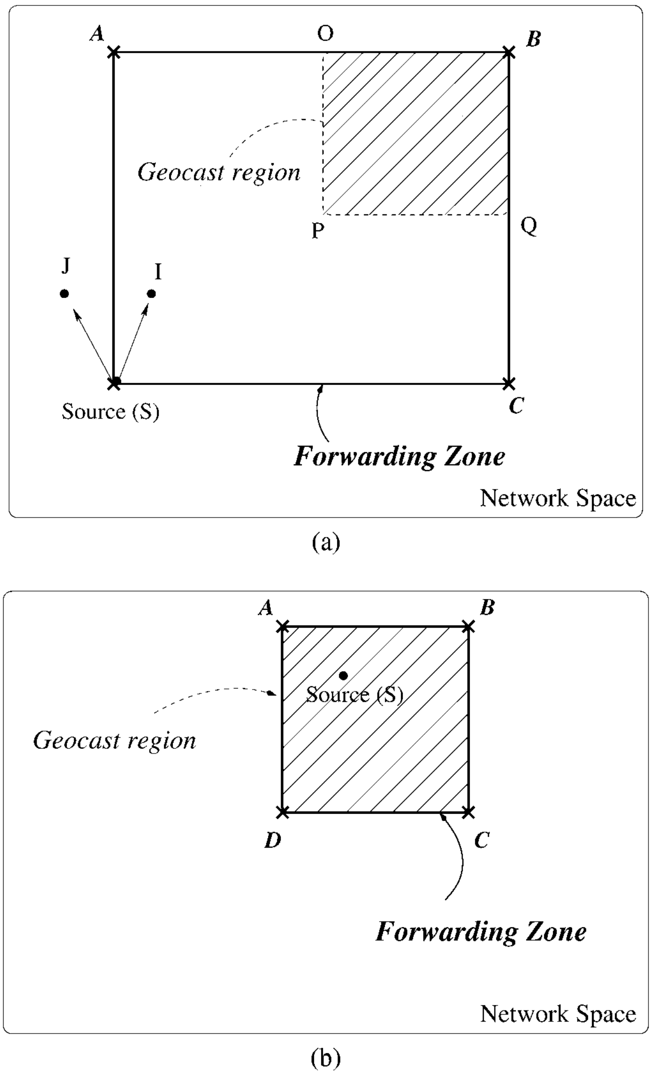


Figure 4. Static zone scheme. (a) Source node outside the geocast region. (b) Source node within the geocast region.

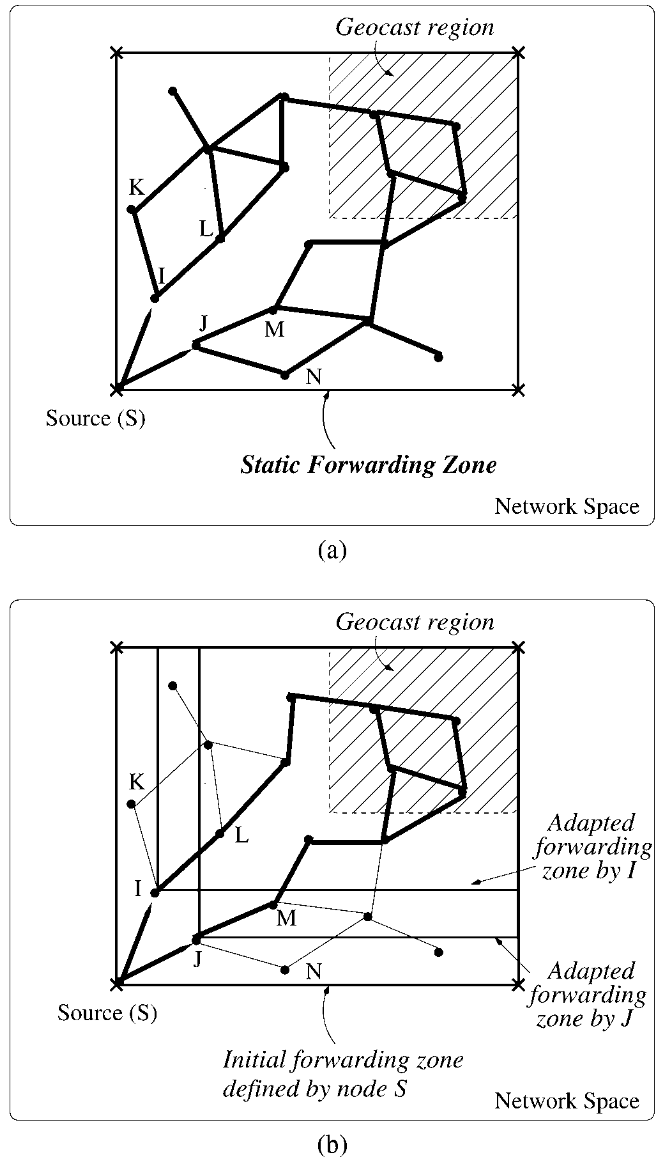


Figure 5. Comparison of static zone scheme and adaptive zone scheme. (a) Static zone scheme. (b) Adaptive zone scheme.

ners are O, P, Q and B, and the forwarding zone is the rectangle whose corners are S, A, B and C. Whereas in figure 4(b), the forwarding zone is identical to the geocast region, as S is within the rectangular geocast region.

The source node S can thus determine the four corners of the forwarding zone. Node S includes their coordinates in a geocast packet transmitted when initiating the geocast delivery. When a node receives the geocast packet, it simply discards the packet if the node is not within the forwarding zone specified by the four corners included in the packet. For instance, in figure 4(a), if node I receives the geocast data packet from another node, node I forwards the packet to its neighbors, because I determines that it is within the rectangular forwarding zone. However, when node J receives the geocast data packet, node J discards the packet, as J is not within the forwarding zone.

Our first scheme is said to be a "static zone scheme", since the forwarding zone specification included in the geocast packet sent by the source node is not modified by any other node (thus, the forwarding zone remains static or unmodified). In the next subsection, we describe a scheme where the forwarding zone is modified by the intermediate nodes.

4.2. Adaptive zone scheme with one-hop flooding

In our "adaptive zone scheme", identical to the static zone scheme, when a node (say, node A) receives a geocast packet, it determines if the packet should be forwarded or not, based on node A's current location and the forwarding zone definition included in the received geocast packet. In the static zone scheme, if node A forwards a geocast packet, the forwarding zone definition in the packet is not modified when the packet is forwarded. On the other hand, using the proposed adaptive zone scheme, when node A forwards a geocast packet, it replaces the forwarding zone specification in the packet by a new specification – the new forwarding zone is determined by node A as the smallest rectangle containing node A and the geocast region such that the sides of the rectangle are parallel to the X and Y axes.

A comparison of the static zone scheme and the adaptive zone scheme is illustrated in figure 5.[5] Figure 5(a) shows a worst case scenario of network topology (assuming no mobility) when using the static zone scheme. Thus, similar to the case of geocast flooding, all nodes in the network get involved in geocast packet delivery from the source node S as they all belong to the forwarding zone, initially determined by node S and unmodified by any other node.

Figure 5(b) shows the proposed adaptive zone scheme with the same topology as the static scheme – assuming no mobility. In figure 5(b), when node I receives a geocast data packet from the source S, node I forwards the packet to its neighbors because I is within the forwarding zone defined by S. When forwarding the packet, node I replaces that forwarding zone by its adapted forwarding zone (see figure) before forwarding the packet. Similarly, node J receiving the packet from node S will determine its own adapted forwarding zone before forwarding the packet to its neighbors. Now, with the adapted forwarding zones newly defined by node I, nodes K and L will make a decision of whether to forward or not. Note that the decision of node K will be negative because it is not within the forwarding zone defined by node I, whereas node L's decision is positive and it will forward the packet after adapting the forwarding zone. By applying the same reasoning, when nodes M and N receive the data packet from node J, node M forwards the packet but node N does not. When node M forwards the packet, the forwarding zone is adapted again. In result, with the adaptive zone scheme, only a subset of nodes receive the geocast packet.

It is important to note that the accuracy of an adaptive zone scheme can be poor in some cases, similar to that illustrated in figure 6(a). The scenario in figure 6(a) differs from the scenario illustrated in figure 5. Unlike figure 5, nodes I and J in figure 6(a) have only one immediate neighbor, nodes K and N, respectively.

When using the above adaptive zone scheme, nodes I and J adapt the forwarding zone before forwarding a geocast packet to their neighbors. When node K receives the packet from node I, node K discards the packet, as K is not within the forwarding zone (as defined by node I). The same happens at node N on receiving a geocast packet from node J. Thus, any packets forwarded by nodes I and J reach a "dead-end", since they are not propagated further. In this particular example, none of the geocast group members in a geocast region will receive the geocast, although there exists a route from the source S to the geocast group members through nodes K and N in figure 6(a).

To improve the accuracy of geocast delivery when using the adaptive scheme, we augment it with "*one-hop flooding*" when necessary – when a node I performs one-hop flooding, all its neighbors consider themselves to be a part of the forwarding zone defined by I. The adaptive zone scheme with one-hop flooding is based on the following rules for forwarding:

[5] In these figures, a bold line connects nodes that have forwarded the geocast packet.

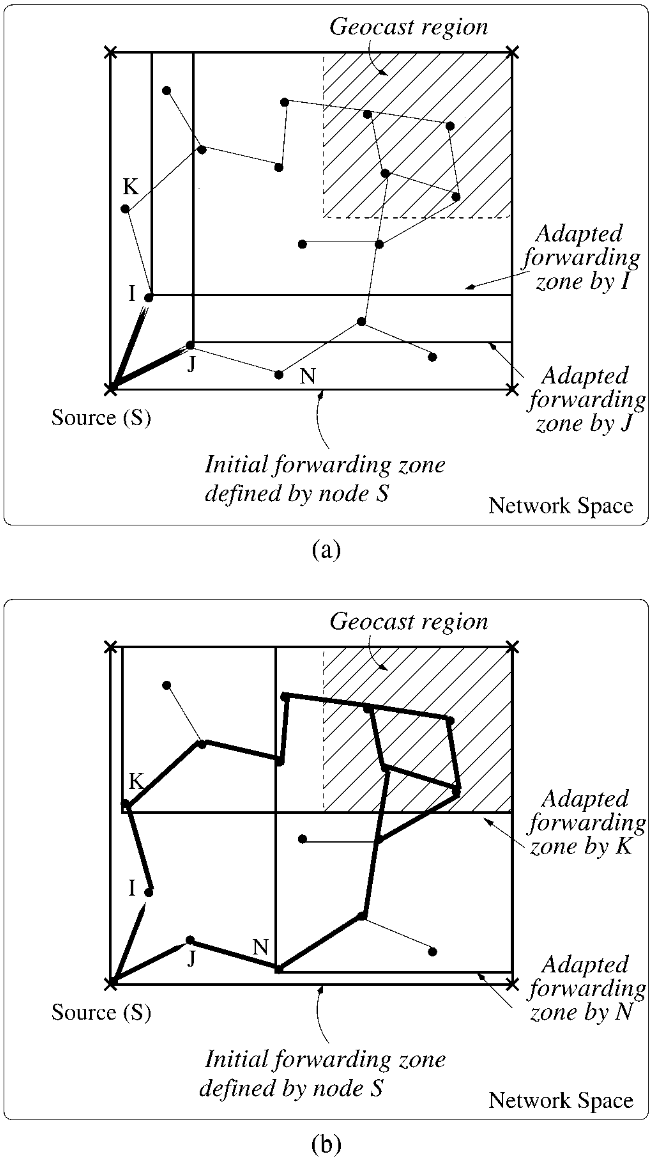


Figure 6. The effect of *one-hop flooding* in the adaptive zone scheme. (a) Unsuccessful geocast delivery when using the adaptive zone scheme. (b) Successfull geocast delivery when using the adaptive zone scheme with one-hop flooding.

- If the forwarding zone defined by any node (say node A) contains at least one immediate neighbor (say node B), then node A includes its adapted forwarding zone in the packet, and forwards the packet to its neighbors.
- Otherwise (i.e., the forwarding zone defined by node A contains no one-hop neighbors), node A performs one-hop flooding to its neighbors by setting the adapted forwarding zone equal to the whole network so that every neighbor of node A will consider itself as a member of node A's forwarding zone.

Figure 6(b) illustrates the adaptive zone scheme augmented by one-hop flooding algorithm. In the figure, when nodes I and J receive a geocast packet from source node S, they calculate the adapted forwarding zone and check to see if at least one of their neighbors exists within the adapted forwarding zone. Since no immediate neighbors are within their adapted forwarding zone, nodes I and J will flood the geocast packet (as per second rule above) to all their immediate neighbors. Of course, the source node S will just drop the packet because it is the initiator of the packet. Now, when nodes K and N receive the geocast packet from I and J, respectively, they do not drop the packet since they belong to the forwarding zone coordinates included in the incoming packet. Then, they again apply the above forwarding rules to the packet. In this fashion, the geocast packet eventually reaches the geocast group members in a geocast region. By selectively using one-hop flooding, the adaptive zone scheme can yield a higher accuracy.

If the adaptive zone scheme does not perform one-hop flooding, then typically, the overhead of the adaptive zone scheme would be lower than that of the static zone scheme. However, when the adaptive scheme performs one-hop flooding, often there are network topologies where the source's original forwarding zone does not contain any neighbors of the source – in such cases, the adaptive zone scheme with one-hop flooding will forward the packet through other neighbors of the source, whereas the static scheme (without one-hop flooding) will not be able to forward the packets at all. Thus, in such cases, the adaptive scheme will result in a higher accuracy than the static scheme. However, it is also important to note that, in such cases, the adaptive scheme will send more geocast packets than the static scheme (since the adaptive scheme is able to forward the packets, while the static scheme is not). Thus, when the adaptive scheme is combined with one-hop flooding, its overhead (i.e., number of geocast packets) may not necessarily be smaller than that of static scheme, though the accuracy of the adaptive scheme would be higher. This discussion suggests that it is important to consider both the overhead as well as the accuracy when comparing two schemes.

4.3. Adaptive distance scheme

In the static or adaptive zone schemes described above, the forwarding zone is explicitly specified in a geocast packet. In the third scheme considered in this paper, named "adaptive distance scheme", node S initially includes three pieces of information with its geocast packet without including the forwarding zone explicitly:

- The geocast region specification.
- The location of the geometrical center, (X_c, Y_c), of the geocast region. Distance of any node Z from (X_c, Y_c) will be denoted as $DIST_Z$ in the rest of this discussion.
- The coordinates of source S, (X_S, Y_S).

When a node I receives the geocast packet from node S, I determines if it belongs to the geocast region. If node I is in geocast region, it accepts the geocast packet. Then, node I calculates its distance from location (X_c, Y_c), denoted as $DIST_I$, and:

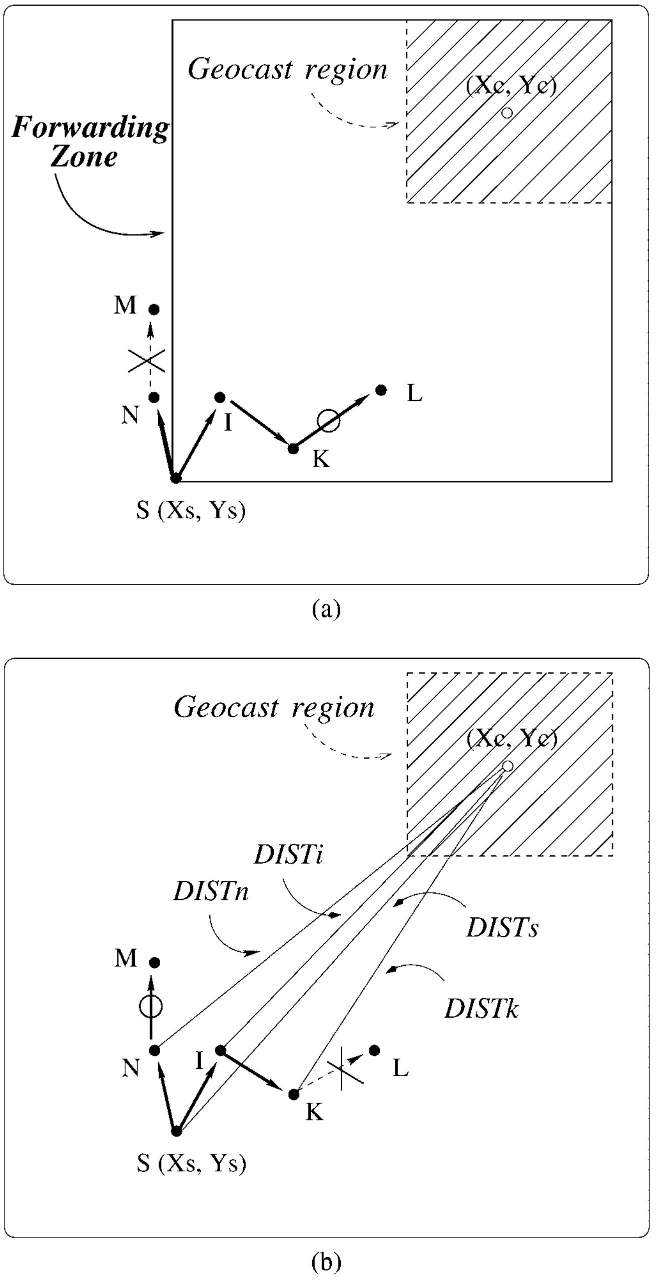


Figure 7. Comparison between static zone scheme and adaptive distance scheme. (a) Static zone scheme. (b) Adaptive distance scheme.

- If $DIST_S \geqslant DIST_I$, then node I forwards the packet to its neighbors. Before forwarding the geocast packet, node I replaces the (X_S, Y_S) coordinates received in the geocast packet by its own coordinates (X_I, Y_I).
- Else $DIST_S < DIST_I$. In this case, node I sees whether or not sender S is within the geocast region. If S is in the geocast region, then node I forwards the packet to its neighbors. Otherwise, I discards the packet.

When some node J receives the geocast data packet (originated by source S) from node I, it applies a criterion similar to above. Thus, node J forwards a geocast packet delivered by I, if J is not farther from (X_c, Y_c) than node I. Node J also forwards the packet in the case when node I is in the geocast region, even if J is not closer to (X_c, Y_c) than I.

Figure 7 illustrates the difference between the static zone scheme and the adaptive distance scheme. Consider figure 7(a) for static zone scheme. When nodes I and K receive the geocast packet (originated by sender S), they forward the geocast packet, as both I and K are within the rectangular forwarding zone. On the other hand, when node N receives the packet, it discards the packet, as N is outside the forwarding zone. Now consider figure 7(b) for adaptive distance scheme. When nodes N and I receive the geocast packet from S, both nodes forward the packet to their neighbors, because both are closer to (X_c, Y_c) than node S. On the other hand, when node K receives the packet from node I, node K discards the packet, as K is farther from (X_c, Y_c) than I. Observe that nodes N and K take different actions when using the two different geocasting protocols.

Similar to the adaptive zone scheme without one-hop flooding augmentation, there is no guarantee to find a route from a source to geocast group members when using the adaptive distance scheme.[6]

5. Performance evaluation

We evaluated the proposed geocasting protocols using an extended version of the network simulator *ns*-2 [2,5]. The *ns*-2 simulator is a widely used discrete event-driven network simulator that was developed as part of VINT project at the Lawrence Berkeley National Laboratory. The extensions implemented by the CMU Monarch project at Carnegie Mellon University – which enable it to accurately simulate mobile nodes connected by wireless network interfaces and multihop wireless ad hoc networks – were used for our simulations. Their extensions also include an implementation of IEEE 802.11 MAC layer protocol and a radio propagation model.

5.1. Simulation model

In our simulation model, the number of nodes in the network was chosen to be 10, 30 and 50 for different simulation runs. Initial locations (X and Y coordinates) of the nodes are obtained using a uniform distribution. The nodes move around in a rectangular region of size 1000 unit $\times$ 1000 unit square according to the following mobility model: each node chooses a direction, moving speed, and distance of move based on a predefined distribution and then computes its next position P and the time instant T of reaching that position. Each node moves with three different *maximum* speeds: 5, 10 and 20 units/s (i.e., average speeds of 2.5, 5 and 10 units/s, respectively). We ran our simulations with movement patterns generated for 6 different pause times: 0, 1, 3, 5, 7 and 9 s. A pause time of 0 s corresponds to continuous motion. The performance of our geocasting protocols is sensitive to a network topology, therefore, we generated scenario files with small variation of pause time, so as to simulate a large number of network topologies.

Two mobile hosts are considered disconnected if they are outside each other's transmission range, which is defined as 250 units for all nodes. The wireless link bandwidth is 2 Mbps. One of the nodes is chosen as the sender for the geocasts – only one source initiates a geocast. In our simulation, simulation time is *inversely* proportional to the speed. For instance, simulations for the maximum speed of 5 units/s run 1000 s of execution, whereas 500 s for maximum speed 10 units/s. As the speed is increased, for a given simulation time, the number of moves simulated increases. If simulation time is kept constant, as speed is increased, a particular configuration (for instance, partition) that may not have occurred at a lower speed can occur at the higher speed. Therefore, we chose to vary simulation time inversely with speed.[7]

A source node generates a geocast data packet every second during the total simulation time of 1000 s, when the maximum speed of each mobile host is 5 units/s. Thus, 1000 geocasts have been done in a simulation run. In our simulation scenario files, a frequency of geocasts is proportional to the speed so that the number of geocasts in each simulation run can be kept constant, regardless of a variation of the speed. For example, when the maximum speed increases into 10 units/s, time between geocasts becomes every 0.5 s. This results 1000 geocasts for 500 s of execution, too.

Finally, the geocast region is defined to be a 300 unit $\times$ 300 unit square (rectangular) region with both X and Y coordinates in the range between 700 and 1000.

5.2. Performance metrics

We use two performance metrics to measure the *accuracy* and *overhead* of geocast delivery.

- *Accuracy of geocast delivery.* We define *accuracy of geocast delivery* as the ratio of the number of group members that actually receive the geocast packet, and the number of group members which were in the geocast region at the time when the geocast delivery was initiated. For example, if only one node among three members of a geocast group actually receives a geocast packet, accuracy of delivery for the geocast will be 33.3%. In our simulation results, we report the average accuracy over all the geocasts performed during the simulation.
- *Overhead of geocast delivery.* The *overhead* is measured in terms of the number of geocast packets *received* by the nodes – the number of geocast packets received by nodes is different from number of geocast packets *sent,* because a single broadcast of a geocast data packet by some node is received by all its neighbors.

[6] In our simulations, we simulate the adaptive zone scheme combined with one-hop flooding. However, the adaptive distance scheme simulated here does not perform one-hop flooding.

[7] On a related note, observe that a configuration that did occur at a lower speed unavoidably lasts a shorter time when the speed is higher.

Specifically, the measure of overhead we use is the *average number of geocast packets received by each node per geocast.* This is calculated by dividing the total number of geocast packets received by all nodes (over a simulation run) by the number of geocast performed, and also by the number of nodes in the system.

When using the geocast flooding algorithm, the highest possible accuracy would be achieved. Note that, even using flooding, it may not be possible to achieve 100% accuracy since some geocast group members may be unreachable from the source. Although geocast flooding can achieve high accuracy, it can potentially deliver the geocast to a large number of hosts that are not in the geocast region. Thus, the overhead of geocast delivery can become significant when flooding is used. In this paper, we consider mechanisms to use location information for the source and the specified geocast region, to reduce the overhead of geocast data delivery.

5.3. Simulation results

We compare the results from the static zone, adaptive zone, and adaptive distance schemes with those from the geocast flooding algorithm. In each graph below, one input parameter (e.g., maximum speed, pause time, or number of nodes) was varied while the other parameters were kept constant.

Accuracy of geocast delivery for 3 proposed geocasting protocols and geocast flooding is depicted in figure 8(a) as a function of maximum speed. Observe that both the adaptive schemes achieve accuracy of geocast delivery almost identical to that of geocast flooding. Static zone scheme provides the lowest delivery accuracy since it does not perform one-hop flooding as in the case of the adaptive zone scheme. Although speed of mobile hosts is increased in figure 8(a), the delivery accuracy does not change much with a variation of speed. This is because the impact for varying speed can be negligible. The only impact speed can have is that the topology might change while a geocast is in progress at higher speed, but not at lower speed. However, probability of this is small, since the speed of node movement is much smaller than speed of message transfer.

Note that in figure 8(a), accuracy of geocast flooding is not 100%. As noted before, in some topologies, some nodes in the geocast region may not be reachable from the source. The actual accuracy depends on the transmission range, since the transmission range determines how well-connected the topology is.

Figure 8(b) plots the overhead, i.e., average number of geocast packets received by a node per geocast, as a function of maximum speed. The overhead is consistently lower for all three geocasting protocols as compared to geocast flooding. Especially, note that the adaptive zone scheme has much less overhead than the adaptive distance scheme and geocast flooding, while it achieves accuracy of geocast delivery comparable with flooding in figure 8(a). That is, the adaptive zone scheme looks much more attractive than all other schemes.

For reasons discussed previously (at the end of section 4.2), the static zone scheme results in a lower overhead,

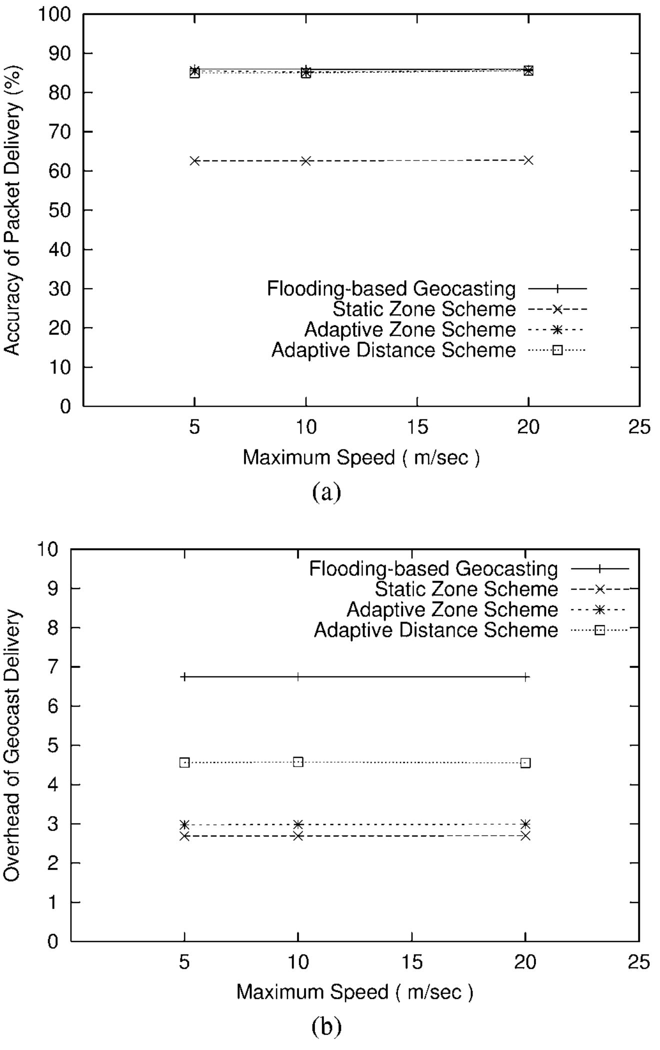
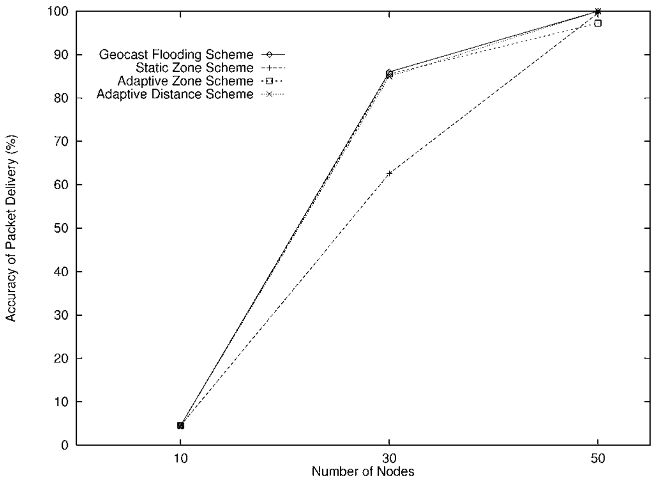


Figure 8. Comparison of three proposed geocasting protocols to geocast flooding with a variation of moving speed (for 30 nodes, and pause time of 0 unit). (a) Delivery accuracy versus speed, (b) delivery overhead versus speed.

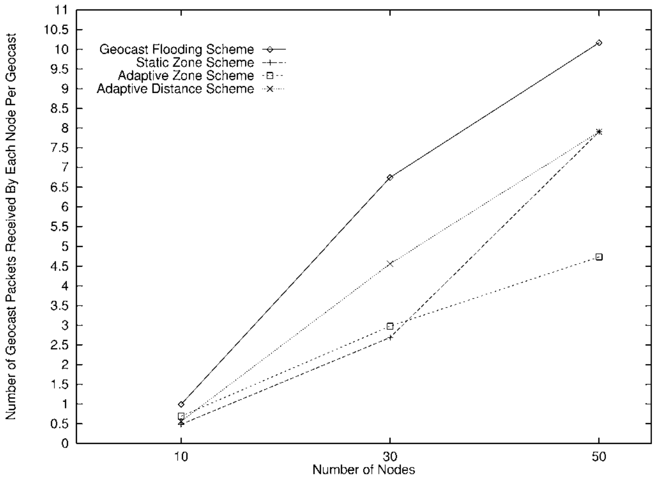
but with a poor accuracy. Therefore, the static zone scheme would typically not be preferred over the adaptive schemes.

The effect of varying the number of nodes is shown in figure 9. With a small number of nodes, all schemes result in a poor accuracy of geocast delivery (see figure 9(a)). With a small number of nodes, the network topology becomes quite sparse, resulting in smaller probability of success of packet delivery to geocast group members. As can be seen in figure 9(a), as number of nodes is increased, the delivery accuracy also begins to increase for all geocasting protocols. Clearly, geocast flooding is the most accurate of all, and the adaptive zone and distance schemes also achieve quite high accuracy. Note that, with a dense network topology of 50 nodes, all schemes show very good accuracy of geocast packet delivery.

Figure 9(b) plots the overhead as a function of the number of nodes. The adaptive zone scheme has smaller overhead than the geocast flooding algorithm – even if the adaptive distance scheme also has competitive overhead when com-

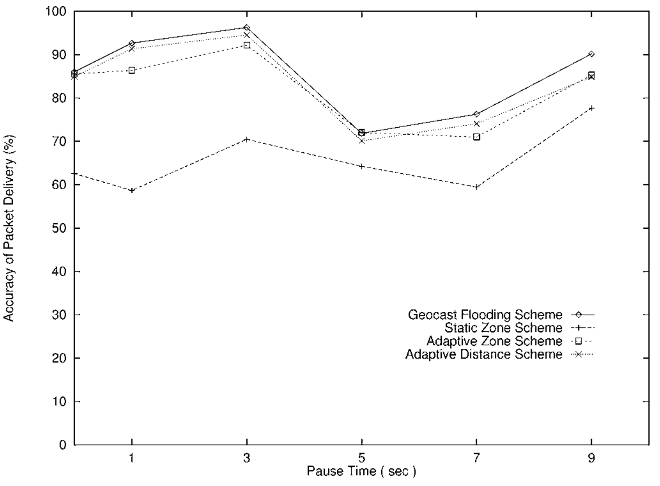


(a)

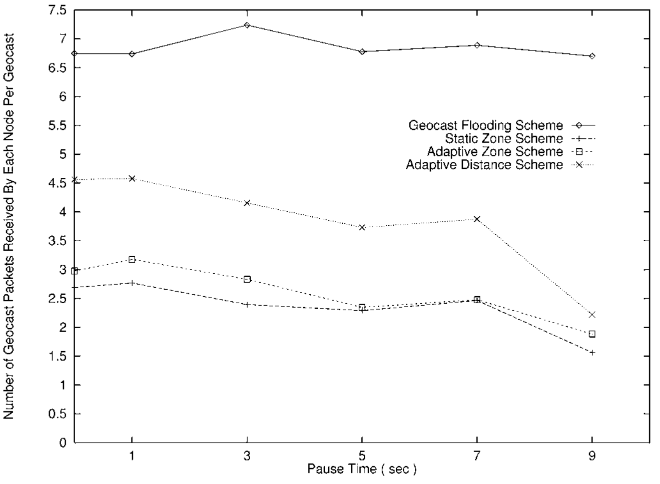


(b)

Figure 9. Comparison of three proposed geocasting protocols to geocast flooding with a variation of node numbers (for pause time 0, and maximum speed of 5.0 units/s). (a) Delivery accuracy versus number of nodes, (b) delivery overhead versus number of nodes.



(a)



(b)

Figure 10. Comparison of three proposed geocasting protocols to geocast flooding with a variation of pause time (for 30 nodes, and maximum speed of 5.0 units/s). (a) Delivery accuracy versus pause time, (b) delivery overhead versus pause time.

pared to geocast flooding, its overhead is consistently larger than that of adaptive zone scheme. Generally, number of geocast packets received per geocast increases with increasing the number of nodes for all schemes. However, both adaptive zone and adaptive distance protocols provide a lower rate of increase than geocast flooding. This is because, with our proposed geocasting protocols, number of geocast packets transmitted is reduced by limiting data broadcasting to a smaller forwarding zone.

Finally, in figures 10(a) and (b), we plot accuracy and overhead of geocast packet delivery with varying pause time. Similar to the results above, both the adaptive zone scheme and the adaptive distance scheme perform much better than the static zone scheme in terms of the accuracy of geocast delivery in figure 10(a). Also, figure 10(b) indicates that message delivery overhead of both adaptive schemes is small when compared to geocast flooding, whereas their accuracies are close to that of geocast flooding.

6. Conclusion

We have considered the problem of *geocasting* – packet delivery to nodes in a specified geographical area – in mobile ad hoc environments. In this paper, the specified geographical area is called the *geocast region*, and the set of nodes that reside within the specified geocast region is called a *geocast group*. This paper proposes three geocasting algorithms: *static zone scheme*, *adaptive zone scheme*, and *adaptive distance scheme*. The proposed geocasting protocols are based on variations of the flooding algorithm. Simulation results indicate that proposed algorithms result in lower message delivery overhead, as compared to geocast flooding. As simulation results show, while reducing the message overhead significantly, using the proposed adaptive algorithms, it is possible to achieve accuracy of geocast delivery comparable with geocast flooding.

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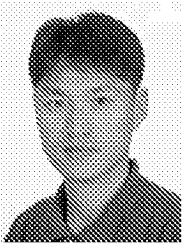

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