Location-Based Multicast in Mobile Ad Hoc Networks *

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Abstract

Multicast distribution in mobile wireless networks is a topic that has recently begun to be explored. For multicasting, conventional protocols define a multicast group as a collection of hosts which register to a multicast group address. However, in this paper, we define a location-based multicast group which is based on a specific region (*"Multicast Region"*) in a mobile ad hoc network (MANET). Hosts within the multicast region at a given time form the multicast group at that time. We present two algorithms for delivering packets to such a multicast group, and present simulation results.

1 Introduction

Multicast distribution in mobile wireless networks is a topic that has recently begun to be explored [22]. When an application must send the same information to more than one destination, multicasting is often used. Multicasting has played an important role in supporting multimedia applications, such as audio/video broadcasting. Multicasting is much more advantageous than multiple unicasts as it reduces the communication costs [8]. Cost considerations are all the more important for a mobile ad hoc network (MANET) consisting of mobile hosts that communicate with each other over wireless links, in the absence of a fixed infrastructure[1] [15, 21]. In MANET, link bandwidth is scarce and topology change is relatively unpredictable.

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[1]We will use the terms *host* and *node* interchangeably.

To do multicasting, some way is needed to define multicast groups. In conventional multicasting algorithms, a multicast group is considered as a collection of hosts which register to that group. It means that, if a host wants to receive a multicast message, it has to join a particular group first. When any hosts want to send a message to such a group, they simply multicast it to the address of that group. All the group members then receive the message.

In this paper, we consider a *location-based multicast group*, which is defined as the set of nodes residing in a geographical "multicast region". Thus, if a host resides within a specific area at a given time, it will be automatically a member of the corresponding multicast group at that time. All the hosts in the multicast region should receive the multicast packet. Such a multicast group may be used for sending a message that is likely to be of interest to everyone at a given location (or in a specified area).

Most existing multicast protocols which have been developed for wired networks [7, 10] cannot be directly applied to the environment of MANET. For instance, source-oriented protocols such as DVMRP [10] would be inefficient because source nodes also can move in mobile ad hoc networks. In addition, an easily reconfigurable multicast tree topology is required since it can be dynamically changed by movement of group members. However, unfortunately, channel overhead caused by tree reconfiguration updates tends to increase very rapidly with mobility [9]. Sometimes, multicast flooding may be a better solution in MANET. In this paper, we propose two *Location-based Multicast* schemes to decrease delivery overhead of multicast packets, as compared to multicast flooding. The schemes in this paper attempt to reduce the forwarding space for multicast packets. Limiting the forwarding space results in fewer multicast messages, while maintaining "accuracy" of data delivery comparable with multicast flooding.

This paper is organized as follows. The next section discusses some related works. Section 3 describes proposed approach for location-based multicasting in MANET. Performance evaluation of our algorithms is presented in Section 4. Finally, Section 5 presents conclusions and future work.

2 Related Work

The closest work to ours is GeoCast by Navas and Imielinski [13, 14, 19]. Their approach is also based on the concept of location-based multicast group. In their scheme, multicast group members are (implicitly) defined as all recipients within a certain region. To support location dependent services such as geographically-targeted advertising, they suggested three methods: geo-routing with location aware routers, geo-multicasting modifying an IP multicast, and application layer solution using extended Domain Name Service(DNS). We suggest a similar concept of location-based multicast group in mobile ad hoc environments.

Metricom is a packet radio system using location information for the routing purpose [18]. The Metricom network infrastructure consists of fixed base stations whose precise location is determined using a GPS receiver at the time of installation. Metricom uses a geographically based routing scheme to deliver packets between base stations. Thus, a packet is forwarded one hop closer to its final destination by comparing the location of packet's destination with the location of the node currently holding the packet.

The algorithms proposed here for multicasting are derived from algorithms we previously proposed for routing in mobile ad hoc networks [16, 17]. In [16, 17], we presented an approach to utilize location information to improve performance of routing protocols in MANET. The key idea behind that scheme is to decrease overhead of route discovery by limiting the search space for a desired route. To do this, the protocol [16, 17] uses physical location information for mobile hosts which may be obtained using the global positioning system (GPS) [11, 20]. Similar ideas have been applied to develop *selective paging* for cellular PCS (Personal Communication Service) networks [4]. In selective paging, the system pages a selected subset of *cells* close to the last reported location of a mobile host. This allows the location tracking cost to be decreased.

3 Location-Based Multicast Protocols

Two approaches may be used to implement location-based multicast:

- Maintain a multicast tree, such that all nodes within the multicast region at any time belong to the multicast tree. The tree would need to be updated whenever nodes enter or leave the multicast region.
- Do not maintain a multicast tree. In this case, the multicast may be performed using some sort of "flooding" scheme. As elaborated below, this is the approach taken in this paper.

  A comparison of the above two approaches is a subject of our current research.

3.1 Multicast Flooding

Flooding is probably the simplest multicast routing algorithm [12]. The flooding algorithm can be used to deliver packets to nodes within a location-based multicast group. The multicast flooding algorithm can be implemented as follows: Assume that a node S needs to send a packet to a specific multicast region – the region would be represented by some closed polygons using geographic coordinates (a circle in Figure 1). Node S broadcasts the multicast packet to all its neighbors[2] – hereafter, node S will be referred to as the *sender* and nodes D, F, and G as the *multicast group members* (note that all nodes present in the specified multicast region are, by definition, multicast group members). A node, say B or C, on receiving the packet, compares the specified region's coordinates with its own location. (We assume that all hosts are able to determine their own location using GPS.) If the location of B is within the specified multicast region, node B will accept the packet. Node B will also broadcast the packet to its neighbors, if it has not received the packet previously (repeated reception of a packet is detected using sequence numbers). If node B is located outside the multicast region, it just broadcasts the packet to its neighbors, if the packet is not a duplicate for node B. In Figure 1, when node X receives the packet from B, it forwards the packet to its neighbors. However, when node X receives the same data packet from C, node X simply discards the packet. Similarly, when node D receives a multicast packet from X, it forwards the packet to its neighbors after accepting the packet.

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

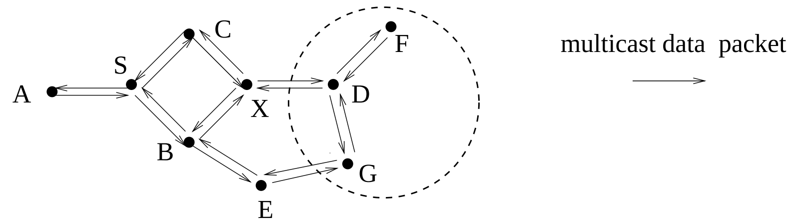


Figure 1: Illustration of multicast flooding

Using the above flooding algorithm, provided that the intended multicast group members are reachable from the sender, the members should eventually receive a multicast message. It is possible that some group members will not receive the packet (for instance, when they are unreachable from the sender, or multicast messages are lost due to transmission errors).

This algorithm would be very simple and robust but would not be very efficient. When using the above algorithm, observe that in the absence of transmission errors, the multicast packet would reach all nodes reachable from the sender S, not just the nodes in the multicast region. Using location information of the source and the specified multicast region, we attempt to reduce the number of nodes, outside the multicast region, to whom a multicast packet is propagated.

3.2 Preliminaries

Location Information

The proposed approach is termed *Location-based Multicast*, as it makes use of location-based multicast groups and utilizes location information to reduce multicast delivery overhead. Location information used in our protocol may be provided by the Global Positioning System(GPS) [2, 3, 11, 20]. Current GPS provides accurate three-dimensional position (latitude, longitude, and altitude), velocity, and precise time traceable to Coordinated Universal Time(UTC) [1]. Therefore, with the availability of GPS, it is possible for a mobile host to know its physical location. (In this paper, we assume that the mobile nodes are moving in a two-dimensional plane.)

In reality, position information provided by GPS includes some amount of *error*, which is the difference between GPS-calculated coordinates and the real coordinates. For instance, NAVSTAR Global Positioning System has positional accuracy of about 50-100 meters and Differential GPS offers accuracies of a few meters [2, 3]. In our discussion, 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 [16, 17].

Multicast Region and Forwarding Zone

Multicast Region: Consider a node S that needs to multicast a message to all nodes that are currently located within a certain geographical region. We call this specific area as *"Multicast Region"*. The multicast region would be represented by some closed polygon such as a circle or a rectangle (see Figure 2). Assume that node S multicasts a data packet at time t_0, and three nodes (X, Y, and Z in Figure 2) are located within the *"multicast region"* at that time. Then, the multicast group G, from the viewpoint of node S at time t_0, would have three members that are expected to receive the multicast data packet sent by node S. Accuracy of multicast delivery can be defined as ratio of the number of group members that actually receive the multicast packet, and the number of group members which were in the multicast region at the time when the multicast is initiated. For example, if only node X among three members of the multicast group G in Figure 2 actually gets a multicast packet, accuracy of delivery for the multicast packet will be about 33.3%.

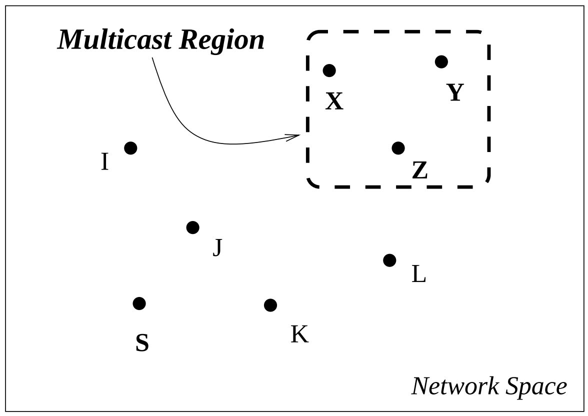


Figure 2: Multicast Region

Forwarding Zone: Again, consider node S that needs to multicast packets to a multicast region. The proposed location-based multicast algorithms use multicast flooding with one modification. Node S defines (implicitly or explicitly) a *"Forwarding Zone"* for the multicast data packet. A node forwards the multicast packet *only if* it belongs to the forwarding zone (unlike the multicast flooding algorithm in Section 3.1).

To increase the probability that a data packet will reach all members in the multicast group, the forwarding zone should include the *multicast region* (described above). Additionally, the forwarding zone may also include other areas around the multicast region. When the multicast region does not include the source node S, a path from S to multicast group members must include hosts outside the multicast region. Therefore, additional region must be included in the forwarding zone, so that node S and other nodes in the multicast region both belong to the forwarding zone (for instance, as shown in Figure 3(a)).

To be a useful multicast protocol, it is necessary to achieve an acceptable accuracy of multicast delivery. Note that accuracy of the protocol can be increased by increasing the size of the forwarding zone (for instance, see Figure 3(b)). However, data delivery overhead also increases with the size of the forwarding zone. Thus, there exists a trade-off between accuracy of multicast delivery and the overhead of multicast delivery.

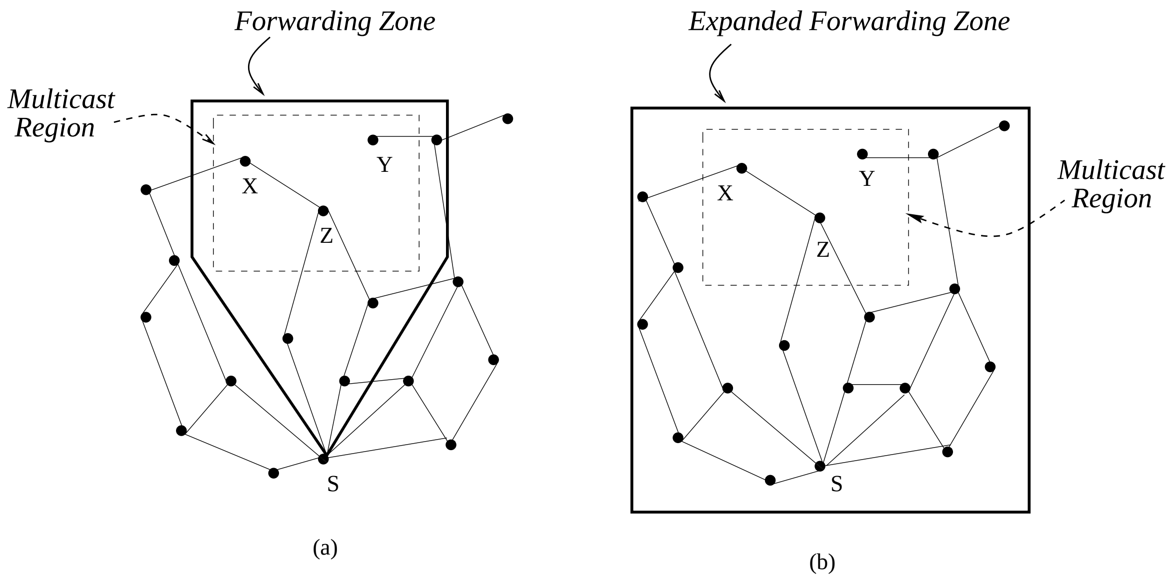


Figure 3: Forwarding Zone: An edge between two nodes means that they are neighbors

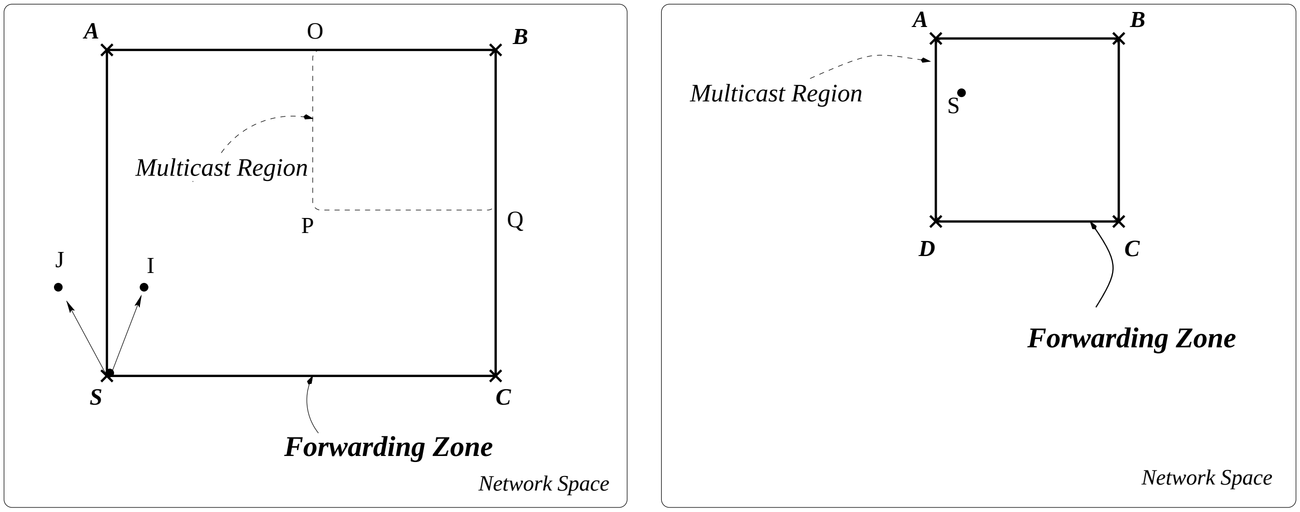
3.3 Determining Membership of the Forwarding Zone

As noted above, the proposed location-based multicast algorithms are essentially identical to multicast flooding, with the modification that a node which is not in the forwarding zone does not forward a multicast packet to its neighbors. Thus, implementing location-based multicast schemes requires that a node be able to determine if it is in the forwarding zone for a particular multicast packet – two algorithms presented here differ in the manner in which this determination is made.

Location-based Multicast Scheme 1

Our first scheme uses a forwarding zone that is rectangular in shape (refer to Figure 4). In our location-based multicast algorithm 1, we define the forwarding zone to be the smallest rectangle that includes current location of node S and the multicast region (the closed polygon region defined previously), such that the sides of the rectangle are parallel to the X(horizontal) and Y(vertical) axes. In Figure 4(a), the multicast region is the rectangle whose corners are O, P, B and Q, 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 multicast region, as S is within the rectangular multicast region.

The source node S can thus determine the four corners of the forwarding zone. Node S includes their coordinates in a multicast packet transmitted when initiating the multicast delivery. When a node receives the multicast packet, it simply discards the packet if the node is not within the rectangle specified by the four corners included in the packet. For instance, in Figure 4(a), if node I receives the multicast 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 multicast data packet, node J discards the packet, as J is not within the forwarding zone (see Figure 4(a)).



(a) Source node outside the Multicast Region

(b) Source node within the Multicast Region

Figure 4: Location-based Multicast scheme 1

Size of the forwarding zone: Note that the size of a rectangular forwarding zone above is dependent on (i) size of the multicast region and (ii) location of the sender. To provide additional control on the size of the forwarding zone, we define a parameter δ, which can be used to extend the forwarding zone. When δ is positive, the rectangular forwarding zone is extended in positive and negative X and Y directions by δ (thus each side increases by 2δ).

For instance, let us consider the case in Figure 4(b). Let us assume a 300 unit x 300 unit square multicast region, such that the sender S is within the multicast region. In this case, the forwarding zone is identical to the multicast region, when δ is set to 0. However, when we use δ = 100 units, the size of the forwarding zone will be larger (500 unit x 500 unit square region). In our simulations, for the purpose of performance evaluation, we use δ in the range of 0 to 150 units.

Location-based Multicast Scheme 2

In the location-based multicast scheme 1 described above, the sender S explicitly specifies the *forwarding zone* in its multicast data packet. In scheme 2, without including the forwarding zone explicitly, node S includes three pieces of information with its multicast packet:

- The multicast region specification.
- The location of the geometrical center, (X_c, Y_c), of the multicast 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 node S, (X_s, Y_s).

When a node I receives the multicast packet from node S, I determines if it belongs to the multicast region. If node I is in multicast region, it accepts the multicast packet.[3] Then, node I calculates its distance from location (X_c, Y_c), denoted as $DIST_i$, and:

- For some parameter δ, if $DIST_s + \delta \geq DIST_i$, then node I forwards the packet to its neighbors. Before forwarding the multicast packet, node I replaces the (X_s, Y_s) coordinates received in the multicast packet by its own coordinates (X_i, Y_i).
- Else $DIST_s + \delta < DIST_i$. In this case, node I sees whether or not node S is within the multicast region. If node S is in the multicast region, then node I forwards the packet to its neighbors. Otherwise, node I discards the packet.

When some node J receives the multicast data packet (originated by node S) from node I, it applies a criteria similar to above: If node J has received this packet previously, it discards the packet. Otherwise, if node J is in the multicast region, it accepts the packet. Also, node J calculates its distance from (X_c, Y_c), denoted as $DIST_j$. Now,

- If $DIST_i + \delta \geq DIST_j$, then node J forwards the packet to its neighbors. Before forwarding the packet, node J replaces coordinates (X_i, Y_i) of node I by its own coordinates (X_j, Y_j).
- Else $DIST_i + \delta < DIST_j$. If node I, which has forwarded the packet to node J, is inside the multicast region, then node J forwards the packet to its neighbors. Otherwise, node J discards the packet.

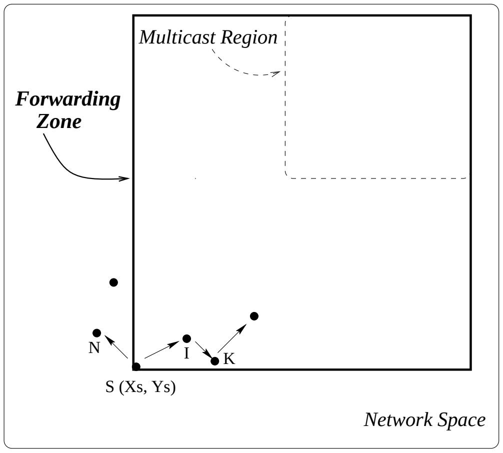
Thus, node J forwards a multicast packet delivered by I (originated by node S), if J is "at most δ farther" from (X_c, Y_c) than node I. Node J also forwards the packet in the case when node I is in the multicast region, even if J is not closer to (X_c, Y_c) than node I. For the purpose of performance evaluation, we use δ in the range of 0 to 150 units in the next section.

Figure 5 illustrates the difference between the two location-based multicast schemes. Consider Figure 5(a) for scheme 1 (assume $\delta = 0$): When nodes I and K receive the multicast packet (originated by node S), they forward the multicast 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 5(b) for scheme 2 (assume $\delta = 0$): When nodes N and I receive the multicast data packet from node S, both forward the packet to their neighbors, because N and I are both closer to (X_c, Y_c) than node S. When node K receives the packet from node I, node K discards the packet, as K is farther from (X_c, Y_c) than node I, and node I is outside the multicast region. Observe that nodes N and K take different actions when using the two location-based multicast schemes.

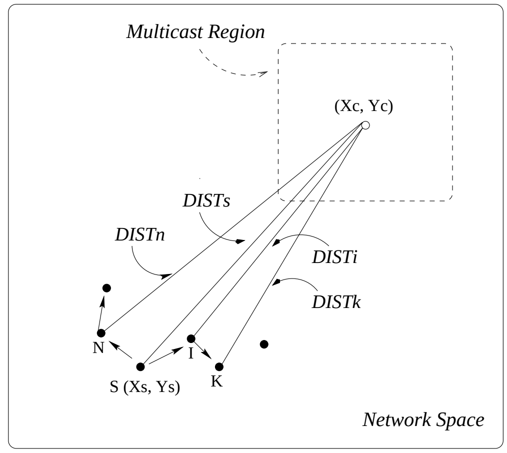
4 Performance Evaluation

To evaluate our schemes, we performed simulations using modified version of a network simulator, MaRS (Maryland Routing Simulator) [5, 6]. MaRS is a discrete-event simulator built to

[3]This test may be modified to see whether node I is in the multicast region, or was in the multicast region *recently*.



(a) Location-based Multicast Scheme 1



(b) Location-based Multicast Scheme 2

Figure 5: Comparison of the two Location-based Multicast Schemes

provide a flexible platform for the evaluation and comparison of network routing algorithms. Three protocols were simulated – multicast flooding, Location-based Multicast scheme 1 and scheme 2. We studied several cases by varying the size of forwarding zone and transmission range of each node.

4.1 Simulation Model

Number of nodes in the network was chosen to be 30. The nodes in the mobile ad hoc network are confined to a 1000 unit x 1000 unit square region. Initial locations (X and Y coordinates) of the nodes are obtained using a uniform distribution. We assume that a node knows its current location accurately.

Also, We assume that each node moves continuously, without pausing at any location. Each node moves with an *average* speed v. The actual speed is uniformly distributed in the range $v - \alpha$ and $v + \alpha$ units/second, where, we use $\alpha = 2.5$. In our preliminary evaluation, we only consider average speed (v) of 2.5 units/sec.

Each node makes several "moves" during the simulation. A node does *not* pause between moves. During a given move, a node travels distance d, where d is exponentially distributed with mean 20. The direction of movement for a given move is chosen randomly. For each such move, for a given average speed v, the actual speed of movement is chosen uniformly distributed between $[v - \alpha, v + \alpha]$. If during a move (over chosen distance d), a node "hits" a wall of the 1000x1000 region, the node bounces and continues to move after reflection, for the remaining portion of distance d.

Two mobile hosts are considered disconnected if they are outside each other's transmission range. All nodes have the same transmission range. For the simulations, transmission range values of 200, 250, 300 and 400 units were used. All wireless links have the same bandwidth, 100 Kbytes per second.

Each simulation run simulated 1000 seconds of execution. For the simulation, a sender is chosen randomly and a multicast region is predefined. We assume that the multicast region is a 300 unit x 300 unit square region with both X and Y coordinates in the range between 500.00 and 800.00. The source performs one multicast per second, which means that 1000 multicasts have been done in each simulation run.

4.2 Simulation Results

In the following, the term "multicast packets" is used to refer to the multicast data packets *received* by the nodes – the number of multicast packets received by nodes is different from number of multicast packets *sent*, because a single broadcast of a multicast data packet by some node is received by *all* its neighbors. We measure two parameters:

- *Accuracy of multicast delivery*

  As explained in Section 3.2, accuracy of multicast delivery is calculated as ratio of the number of multicast group members which actually receive the multicast packets, and the number of group members which were supposed to receive the packets. In our simulation results, the accuracy of multicast delivery is an average over 1000 multicasts.

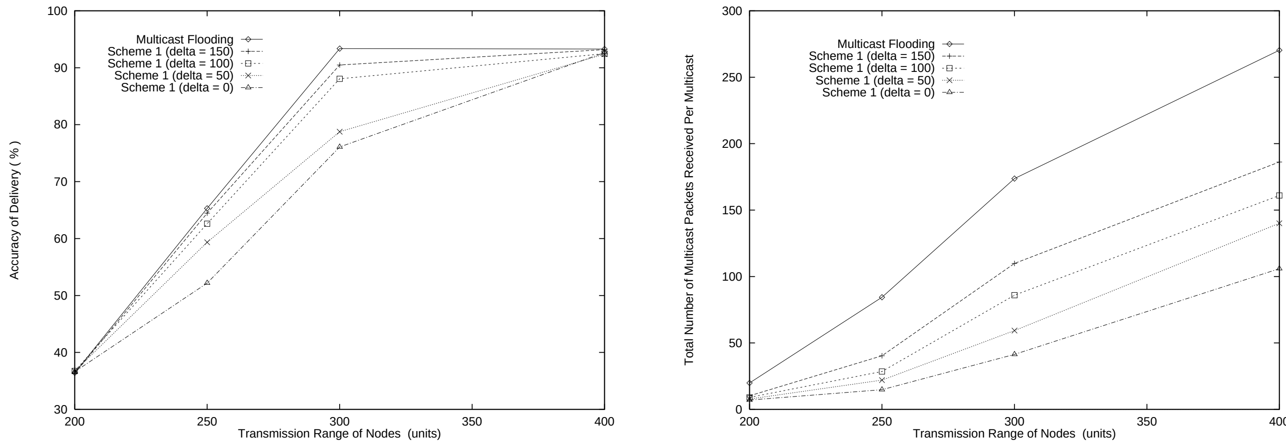
- *Total number of multicast packets received by nodes* per multicast

  This is defined as the total number of multicast packets delivered to all the nodes combined, during each multicast. Note that when a node broadcasts a packet to its neighbors, the packet is delivered to all its neighbors (and counted as many times in this statistic). The number of multicast packets received by the nodes per multicast is a measure of the overhead of multicast packet delivery.

We compare the results from location-based multicast schemes 1 and 2 with those from the multicast flooding algorithm.

Accuracy of multicast delivery for the location-based multicast scheme 1 is depicted in Figure 6(a) as a function of transmission range of each node. Figures 6(a) also shows how the size of forwarding zone, i.e., varying the value of δ in the range of 0 to 150 units, affects accuracy. Generally, the accuracy of scheme 1 increases with increasing δ. Note that, when δ is equal to 150, accuracy of multicast delivery for scheme 1 is almost the same as that for multicast flooding. In some cases, accuracy of multicast flooding itself is not too good. With a smaller transmission range, number of neighbors for each node decreases. Therefore, a single broadcast of multicast packet results in less nodes receiving the packet. This factor contributes to a decrease in probability that the packet reaches multicast group members.

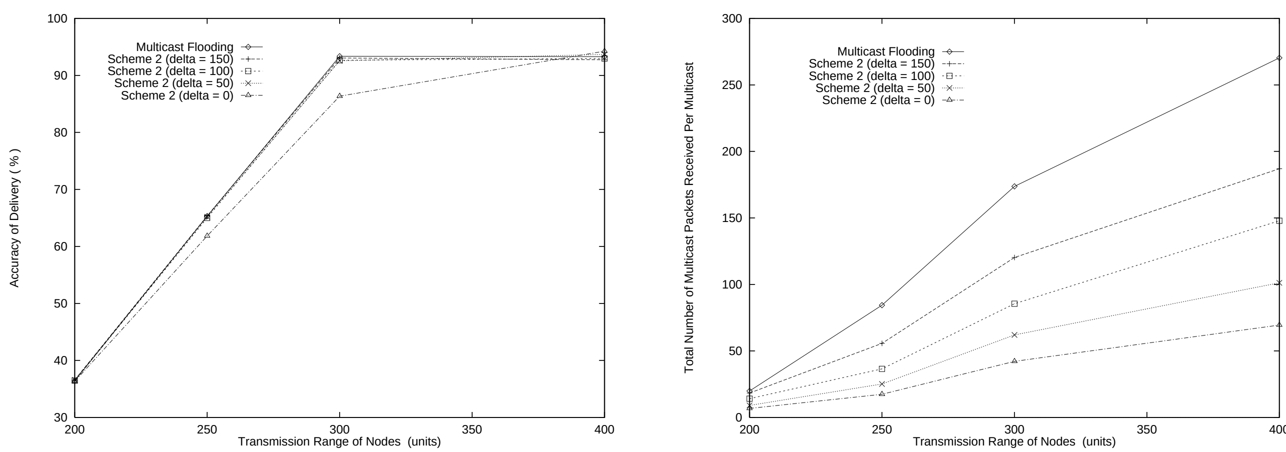
Figure 6(b) plots the total number of multicast packets received by the nodes per multicast as a function of transmission range of each node. Observe that the number of multicast packets received is consistently lower for the location-based multicast scheme 1 as compared to multicast flooding. As the transmission range of nodes is increased, number of multicast packets received per multicast increases for all schemes. However, scheme 1 provides a lower



(a) Accuracy of Multicast Delivery

(b) Total Number of Multicast Packets Received Per Multicast

Figure 6: Location-based Multicast Scheme 1 (For 30 nodes, and Average speed 2.5 units/sec) : (a) Delivery accuracy versus Transmission range, (b) Total number of multicast packets received per multicast versus Transmission range



(a) Accuracy of Multicast Delivery

(b) Total Number of Multicast Packets Received Per Multicast

Figure 7: Location-based Multicast Scheme 2 (For 30 nodes, and Average speed 2.5 units/sec) : (a) Delivery accuracy versus Transmission range, (b) Total number of multicast packets received per multicast versus Transmission range

rate of increase than multicast flooding. This is because, with scheme 1, number of multicast packets transmitted is reduced by limiting data broadcasting to a smaller forwarding zone.

Figure 7 plots the results for scheme 2. Figure 7(a) shows that the location-based multicast scheme 2 is generally more accurate than scheme 1 (See Figure 6(a)). However, note that the accuracy for schemes 1 and 2 both is comparable with that of the multicast flooding, when $\delta = 150$ units. Similar to scheme 1, amount of multicast data delivery overhead for the multicast flooding algorithm increases much more rapidly than scheme 2, when transmission range is increased. The effect of varying the size of forwarding zone is also shown in Figure 7.

5 Conclusion

This paper focuses on location-based multicasting problems in mobile ad hoc environments. A location-based multicast group is defined as the set of nodes that reside within a specified *multicast region*. We propose two location-based multicast algorithms. The proposed algorithms limit the forwarding space for a multicast packet to the so-called *forwarding zone*. Simulation results indicate that proposed algorithms result in lower message delivery overhead, as compared to multicast flooding. As simulation results show, while reducing the message overhead significantly, it is possible to achieve accuracy of multicast delivery comparable with multicast flooding. A comparison between proposed algorithms and an alternative approach maintaining a multicast tree to implement location-based multicast is a topic for further work.

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