Fuzzy Controlled Adaptive Geocasting in Mobile Ad Hoc Networks

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Abstract—Geocasting is a variant of conventional multicasting problem. For multicasting, protocols define a multicast group as a collection of hosts which register to a multicast group address. However, for geocasting, the group consists of the set of all nodes within a specific geographic region. Hosts within the specific region at a given time, form geocast group at that time. Here we present an adaptive, performance-oriented procedure for delivering packets to such a group. Simulation results and accompanied mathematical analysis emphasize the efficiency of our proposed scheme compared to other location-based multicast algorithms evolved earlier.

Keywords—AC-zone, Adaptive, Fuzzy-controller, Geocasting, Multicasting.

I. INTRODUCTION

When an application desires to transmit same information to more than one destination, multicasting is often used because it is very advantageous in comparison to multiple unicasts in terms of communication costs. Cost consideration is all the more important for a mobile ad hoc network consisting of mobile hosts that communicate with each other via wireless links, in absence of any fixed infrastructure [2]. In this environment the multicast problem is even more complex because topology change of the network is extremely dynamic and unpredictable [2-12, 21, 25].

In conventional multicasting, a multicast group is defined to be a collection of nodes which register to that group. When any host wants to send a message to all members of such a group, the node simply multicasts it to address of the group. In the present article, we consider a different approach named Geocasting. A geocast message [13-20, 24, 25] is delivered to the set of nodes within a specific geographical area. We refer to the specific area as “geocast region” and set of nodes within the region as “geocast group” or “location-based multicast group”. If a host resides within a geocast region at a time, it will automatically become a member of the respective multicast group consisting of all nodes within the bounded region. A geocast group may be used for sending a message that is likely to be of interest of everyone in a specified area. However, it may be noted that at any point of time, a node may be member of more than one geocast group.

Two fundamental approaches for multicasting are multicast flooding and multicast tree based communication. Existing protocols, [7, 8, 14, 22] mainly built on later approach, may not work well in mobile ad hoc environments as dynamic movements of group members can cause frequent tree reconfiguration with excessive channel overhead and loss of datagrams. Since the task of keeping the structure up to date in the multicast tree based communication is non-trivial, sometimes flooding may be considered as an alternative approach for multicast communication [13-20, 22, 24, 25].

The adaptive geocasting scheme presented in this article, produce optimal success rate of message delivery at minimum possible cost. All nodes belonging to the geocast region, at the time of initiation of some geocast operation, at least receive the notification that they are members of a certain geocast group (group identifier specified) and they are intimated with an advice to stay within a logically bounded portion of network area – termed as "accuracy-control zone or AC-zone" for a precomputed time period provided they feel interested to receive the message. Size and shape of the AC-zone is revised on a per-packet basis. Empirical findings presented in section IV, strongly support the merit of our proposed geocast communication procedure.

II. Adaptive Geocasting In Detail

A. Location Information

The proposed approach is termed as location based multicast as it utilizes location information to reduce multicast delivery overhead. Here in this article, we shall use the terms 'geocast' and 'multicast' interchangeably. Location information used in our protocol has been provided by global positioning system (GPS) [1]. With the availability of GPS, it is possible for a multicast host to know it's physical location (expressed as an ordered pair of latitude and longitude). In reality, position information provided by GPS includes some amount of error, which is the difference between GPS calculated coordinates and 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 [1]. In our discussion, we assume that each host knows it's actual position precisely (i.e. no error).

B. Geocast Region

Consider a node n_s that needs to multicast a message to all nodes currently located within a certain geographic region. We call this specific area as "Geocast Region". The region is represented by some closed polygonal area (see fig. 1). Here in the present article, we demonstrate performance of the adaptive geocasting procedure with respect to a rectangular geocast region and then, according to the Sandwich theorem by T. M. Apostol [26], generalize it for any arbitrary closed shape. Specification of a geocast region consists of coordinates of it's peripheral vertices. Assume that node n_s (source may or may not be within the geocast region) geocasts a data packet at time t_0 and three nodes (n_x, n_y and n_z in fig. 1) are located within the geocast region at that time. Then the geocast group from the viewpoint of node n_s at time t_0, would have three members that are expected to receive the multicast delivery sent by node n_s.

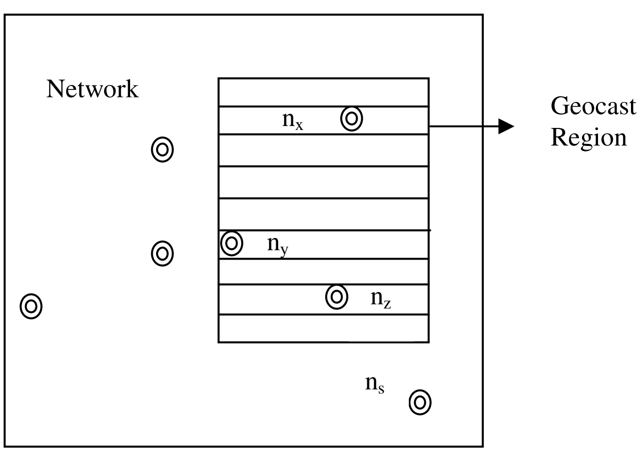

Fig.1. Geocast Region

Accuracy of the multicast delivery is defined as the ratio of the number of group members actually receiving the packet and number of group members which were in the multicast region at the time of initiation of multicast. For example, if only node n_x, among three members of the multicast group in fig. 1, actually gets a multicast packet, accuracy of delivery for the multicast packet will be 33.3%.

C. Accuracy Control (AC) zone

In order to increase the probability that a multicast data packet will reach all members of multicast group at minimum cost, the concept of accuracy control zone has been introduced in the present article. It is a fuzzy-logic computed (initially rectangular; modification of its shape after transmission of each message packet is illustrated in section II E) surrounding around, either the geocast region if it is rectangular or around the smallest rectangle enclosing the geocast region if it (geocast region) is not rectangular. For example, in fig. 2, AC zone is collectively formed by four independent rectangular partitions $A_1B_1B_1'A_1'$, $A_1'ADD_1'$ $BB_1'C_1'C$ and $D_1'C_1'C_1D_1$, corresponding to the geographical region ABCD which is either the geocast region itself or the smallest rectangular surrounding around the geocast region. Territory of these partitions are determined by the following requirement specifications:

1. A member of the multicast group leaving the geocast region without receiving any packet of information message, is expected to receive the intimation about occurrence of a geocast transmission (alert message) identified by a triple (id_s, τ, mm_s) where id_s is the unique identification number of the source, τ denotes the corresponding timestamp and mm_s is the message identification number, unique w.r.t. the source, by at least one node in AC zone.
2. For a multicast member receiving at least one message packet, Euclidean coordinate position until arrival of the next message packet, have to be bounded by the newly computed (corrected) AC zone.

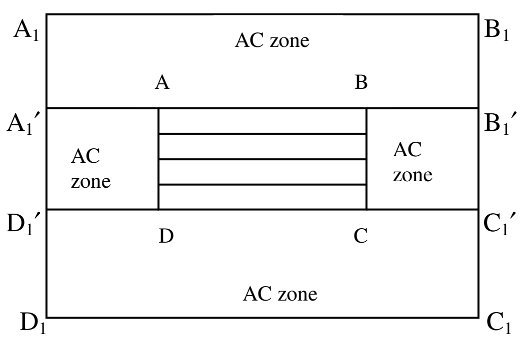

Fig.2 Demonstration of AC zone

D. Preliminary Shape And Size Of AC zone

Our analysis on computation of co-ordinates of peripheral vertices of AC zone is based on the Reliability Fuzzy Controller (RFC). It accepts five input parameters (associated to each hop) namely, (1) radio-proportion, (2) proximity, (3) entropy, (4) link strength, (5) neighbor-update interval and produces one single output reliability. Initially, sender node transmits "alert" message directly towards the geocast region in a straight line. Let, $n_a \rightarrow n_b$ in fig. 3 indicate the reliable hop nearest to geocast region i.e. farthest from the sender. Then, determination of initial shape and size of AC zone begins as a clockwise traversal around geocast region from n_b. Assuming that $n_j \rightarrow n_i$ in fig. 3 is the most recent reliable hop during the clockwise traversal, determination of respective boundary of AC zone proceeds like this: n_i broadcasts alert message to its neighbors in forward direction of clockwise traversal around the geocast region (or smallest rectangle around geocast region) and finds the connectivity with, say, n_k as the most reliable among others. Then, the respective (top/ bottom/ left/ right) boundary is set depending upon the Euclidean coordinates of n_k. If n_k is on or within the boundary of AC zone estimated so far, its coordinate remains ineffective;

otherwise, left (right) boundary of AC zone is set to X coordinate of n_k or top (bottom) boundary of AC zone is set to Y coordinate of the same node. Clockwise traversal now continues from n_k till the virtual perpendicular from n_b to the geocast region is reached. Algorithmic representation of the procedure can be found in fig. 4. It takes care of all possible scenarios of position of the sender with respect to the geocast region (sender may be within the geocast region or if it is outside, it may be nearest to the left/right/top/bottom edge of the geocast region; sender may also be equidistant from two edges of geocast region nearest to it).

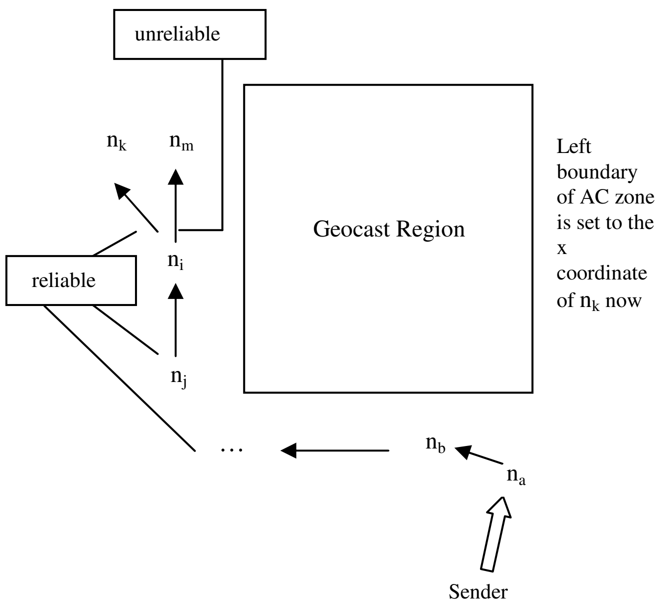

Fig.3. Preliminary size of AC zone

```
struct position { int x,y; };
struct list { struct poition pos; int idnum; struct list* next;};
struct node { struct poition pos; int idnum; struct list* neighbors;};
struct list* boundary_nodes=NULL;
/* boundary_nodes is pointer to a list of nodes supposed to participate in determination of boundary of AC zone */

Procedure init ( node ns )
  begin
    /* ns is sender of the geocast message */
      node nb; struct position geo_blpt, geo_trpt;
     /* geo_blpt :bottom left point of geocast region;
      geo_trpt :top right point of  geocast region */
         scan geo_blpt.x, geo_blpt.y, geo_trpt.x, geo_trpt.y;
         nb = clk_trv (ns,geo_blpt, geo_trpt);
        /* clk_trv is a function that returns the node from where clockwise traversal around geocast
           region should begin */
        append (nb, boundary_nodes) ;
        size_AC (ns, nb, geo_blpt, geo_trpt);
      end proc

 Procedure size_AC ( node ns, nb, position geo_blpt, geo_trpt)
   begin
```

```
/* n_i is the most recently selected reliable node */
int stat = -1;  position minpos, maxpos;
/* stat is an integer variable specifying whether the clockwise traversal around the geocast region has been completed or not */
/* (minpos.x, minpos.y) : bottom-left coordinate of AC zone */
/* (maxpos.x, maxpos.y) : top-right coordinate of AC zone */
node n_dep, n_temp, n_st; char rel_max, rel_cur;
/* n_dep is the next dependable node; n_temp is a temporary node type variable; n_st = n_b */
/* rel_max indicates the maximum of fuzzy reliability of wireless connections between most recently determined reliable node and its neighbors in forward direction of clockwise traversal around geocast region */
/* rel_cur is the fuzzy reliability of wireless connection between most recently determined reliable node and one of its neighbors in forward direction of clockwise traversal around
geocast region */
rel_max = 'a' ;
if ( n_i = n_b ) then n_st = n_i ; end if
for all n_temp ∈ N_i^c(t_2) /* N_i^c(t_2) is the set of neighbors of node n_i at time t_2 in the forward direction of clockwise traversal; current time is denoted by t_2 */
   begin
     send_msg ("alert", n_i, n_temp) ; /* broadcast alert message to all members of N_i^c(t_2) */
     rel_cur = fuzz_rel (n_i, n_temp) ;
     /* fuzz_rel computes reliability of a wireless bond between a node and its specified neighbor, using fuzzy rule bases of RFC to be described in this section */
     if ( rel_cur ≥ rel_max) then
      begin
        rel_max = rel_cur; n_dep = n_temp ; end if
 end for
append (n_dep, boundary_nodes);
stat = chk_status (n_st, n_i, n_dep, geo_blpt, geo_trpt);  /*chk_status is a function that returns 1 if the hop n_i → n_dep completes the clockwise traversal around geocast region; otherwise it returns 0 */
if ( stat = 0) then size_AC (n_s, n_dep, geo_blpt, geo_trpt);
else lim_AC ( boundary_nodes, &minpos, &maxpos );  end if /* minpos.x : minimum of x coordinates of all nodes in boundary_nodes */
/* minpos.y : minimum of y coordinates of all nodes in boundary_nodes */
/* maxpos.x : maximum of x coordinates of all nodes in boundary_nodes */
/* maxpos.y : maximum of y coordinates of all nodes in boundary_nodes */
end proc

function chk_status ( node n_start, n_i, n_dep, position geo_blpt, geo_trpt)
  begin
   int l = edg_mindist (n_start, geo_blpt, geo_trpt) ;
 /* edg_mindist is a function that finds out the edge of geocast region nearest to n_start */
switch (l)
   begin
    case 1:  /* nearest edge is bottom most edge */
            if (n_dep.pos.x ≤ n_start.pos.x and n_start.pos.x ≤ n_i.pos.x)
            return 1; else return 0; end if
    case 2:  /* nearest edge is top most edge */
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                if (n_i.pos.x ≤ n_start.pos.x and n_start.pos.x ≤ n_dep.pos.x)
                return 1; else return 0; end if
     case 3:  /* nearest edge is left most edge */
               if (n_i.pos.y ≤ n_start.pos.y and n_start.pos.y ≤ n_dep.pos.y)
               return 1; else return; end if
     case 4:  /* nearest edge is right most edge */
               if (n_dep.pos.y ≤ n_start.pos.y and n_start.pos.y ≤ n_i.pos.y)
               return 1; else return 0; end if
  end switch
end function

function edg_mindist (node n_start, position geo_blpt, geo_trpt)
  begin
     int d1, d2, d3, d4, aux1, aux2, edg1, edg2, minedg;
     d1 = abs(n_start.pos.y – geo_blpt.y); /* d1 is distance of n_start from bottom-most edge of geocast region */
     d2 = abs(n_start.pos.y – geo_trpt.y); /* d2 is distance of n_start from top-most edge of geocast region */
     d3 = abs(n_start.pos.x – geo_blpt.x); /* d3 is distance of n_start from left-most edge of geocast region */
     d4 = abs(n_start.pos.x – geo_trpt.y); /* d4 is distance of n_start from right-most edge of geocast region */
     if ( d1 < d2 ) then begin aux1 = d1; edg1 = 1; end
     else begin aux1 = d2; edg1 = 2;  end if
     if ( d3 < d4 ) then begin aux2 = d3; edg2 = 3; end
      else begin aux2 = d4; edg2 = 4; end if
     if ( aux1 < aux2) then minedg = edg1;
     else minedg = edg2; end if
       return(minedg);
     end function

function clk_trv (node n_s, position geo_blpt, geo_trpt)
  begin
    int stat = 0; char rel_cur, rel_max = ‘a’; node n_temp, n_ret, n_dep;
    if(not(clip(n_s,geo_blpt, geo_trpt))) then begin /* source is not within geocast region */
     for all n_temp ∈ N_s^g(t_1) and (not(clip(n_s,geo_blpt, geo_trpt)))
       begin
         stat = 1; send_msg (“alert”, n_s, n_temp);  /* N_s^g(t_1) is the set of neighbors of n_s during its journey towards
the geocast region ; t_1 is the current time */
         rel_cur = fuzz_rel (n_s, n_temp);
         if (rel_cur > rel_max) then
          begin rel_max = rel_cur; n_dep = n_temp; end if
end for
if (stat = 1 and rel_max > ‘b’ ) then
nret = clk_trv (node n_dep , geo_blpt, geo_trpt);
 else n_ret = n_s; end if
 return (n_ret);
 else begin
   for all n_temp∈ N_s^g(t_1) begin
    if (not(clip(n_s,geo_blpt, geo_trpt))) then  begin
      stat = 1; send_msg (“alert”, n_s, n_temp);  /* N_s^g(t_1) is the set of neighbors of n_s during its journey towards
the geocast region ; t_1 is the current time */
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        break; end if end for
 if (stat = 1) then n_ret = clk_trv (node n_temp , geo_blpt, geo_trpt);
  else begin
  choose any n_temp∈ N_s^g(t_1)
  send_msg ("alert", n_s, all n_temp);
  n_ret = clk_trv (node n_temp , geo_blpt, geo_trpt); end if
end function

function clip (node n_tm, position geo_blpt, geo_trpt)
  begin
    if(geo_blpt.x ≤ n_tm.pos.x and n_tm.pos.x ≤ geo_trpt.x and geo_blpt.y ≤ n_tm.pos.y and n_tm.pos.y ≤
geo_trpt.y) then return(1); else return(0); end if
end function
```

Fig.4. Algorithm for determination of AC zone

Description of parameters of RFC are shown below:

1. Radio-proportion – For accuracy of multicast delivery, nodes on peripheral edges of AC zone should be equipped with as high radio-range as possible. This will enhance the possibility that a multicast member leaving the geocast region without receiving the message, falls within the neighborhood circle of a node in AC zone. Let, radio-proportion of a node with radio-range R_w is denoted by γ^* and defined as follows:

$$\gamma^* = (R_w - R_n) / (R_m - R_n) \qquad (1)$$

where R_n and R_m denote the minimum and maximum possible radio ranges in the network at that point of time. These information are assumed to be stored in each and every network element. It is clear from definition of γ^* in (1) that $0 \leq \gamma^* \leq 1$ as $R_n \leq R_w \leq R_m$. Higher values of γ^* (closer to 1) positively contribute to increase the multicast throughput.

2. Proximity – Proximity $P^*_{ij}(t)$ of a component hop from any arbitrary node n_i to another node n_j on an edge of AC zone at time t is computed as follows.

$$P^*_{ij}(t)=\begin{cases}(1 - \delta_{ij}(t) / f(R_i, R_j)) & \text{if } 0 < \delta_{ij}(t) \leq f(R_i, R_j) \\ (1-\delta_{ij}(t) / R_i)^{(Ri,-Rj) / (\delta ij(t)-Rj)} & \text{otherwise}\end{cases} \qquad (2)$$

$$\text{where } f(R_i, R_j) = \begin{cases} R_i & \text{if } R_i \leq R_j \\ R_j & \text{otherwise}\end{cases}$$

$\delta_{ij}(t)$ indicates Euclidean distance between n_i and n_j at time t. Since n_j is a neighbor of n_i, obviously $\delta_{ij}(t) \leq R_j$. From this we can see that $0 \leq P^*_{ij}(t) \leq 1$. If $0 < \delta_{ij}(t) \leq f(R_i, R_j)$, it indicates that both n_i and n_j are within the neighborhood of one another; hence, any multicast member passing between n_i and n_j falls within neighborhood of both and hence accuracy of the multicast delivery increases with higher expectation in context of the criterion of difference in neighbor update intervals of n_i and n_j. On the other hand, if $\delta_{ij}(t) > f(R_i, R_j)$, it automatically implies that n_j is within neighborhood of n_i but not vice-versa. In this case, acknowledgement from n_j will have to traverse a multi-hop path to n_i. These kind of loosely connected hops are also taken into consideration because transmission of alert message takes place uni-directionally, from n_i to n_j, during

initial structural formation of AC zone. In order to ensure comparatively lesser weight to such situations $(R_i-R_j)/(\delta_{ij}(t)-R_j)$ has been raised to the power of $(1-\delta_{ij}(t)/R_i)$ in the formulation of P*, because $(1-\delta_{ij}(t)/R_i)\leq 1$ and $(R_i-R_j)/(\delta_{ij}(t)-R_j) \geq 1$. This is expressed using the figures 5a and 5b.

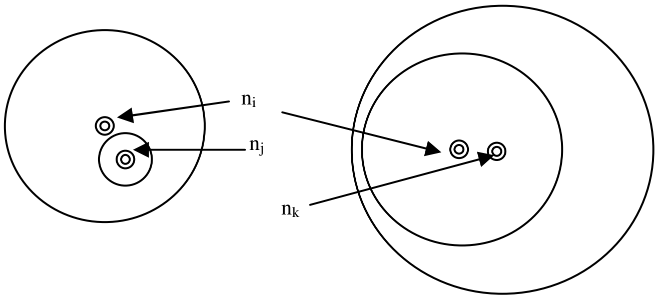

Fig.5a. Proximity between n_i and n_j Fig.5b. Proximity between n_i and n_k

Assuming $R_i = 10$, $R_j = 3$, $R_k = 20$ and $\delta_{ij}(t) = \delta_{jk}(t) = 5$, according to fig. 5a, proximity of the wireless connection n_i to n_j is $(1\text{-}5/10)^{(10-3)/(5-3)}$ i.e. $0.5^{3.5}$ and the same for the wireless connection between n_i to n_k is $(1\text{-}5/10)$ i.e. $0.5 > 0.5^{3.5}$. Physical significance of the example phenomenon is that, if a node has two equidistant neighbors, proximity of that particular neighbor should dominate where one communicating node is within radio-range of the other. Higher proximity between consecutive nodes, is greatly advantageous for success of geocast operation.

3. Entropy – Measurement of entropy around a node in this article is based on the relative velocity of a node w.r.t. it's neighbors. Let, velocity vectors (including both speed and direction) for any two nodes n_i and n_{i+1} at time t, be $v_i(t)$ and $v_{i+1}(t)$. The relative velocity $v_{i,i+1}(t)$ of n_i w.r.t. n_{i+1} at time t is given by

$$v_{i,i+1}(t) = v_i(t) - v_{i+1}(t)$$

Relative velocity of n_i w.r.t. n_{i+1} during some time interval Δt, is expressed as their absolute relative speed averaged over time Δt, i.e.

$$v_{avg}(i, i+1) = (1/w) \sum_{j=1}^{w} | v_{i,i+1}(t_j) |$$

where w is the number of times t_j, up to which the past velocity statistics of n_{i+1} can be disseminated to n_i embedded within the acknowledgement to hello message, for the time interval Δt. Although, actually, velocity has a continuous distribution bounded by a specific minimum (in most of the cases it is 0) and maximum [21, 22], it has been discretized here for simplification of the determination of entropy. Based on this, entropy H^*_i at mobile node during time interval between t and t+Δt is calculated as

$$H^*_i(t+\Delta t) = \sum_{n_k \in N_i(t)} H^*_{i,k}(t+\Delta t) \qquad (3)$$

where,

$$H^*_{i,k}(t+\Delta t) = \begin{cases} \left[\dfrac{P'(n_k,t,\Delta t)}{\log(|N_i(t)|)}\right]^{1/(\rho|N_i(t)|)} & \text{if } C^1(n_k,t)=1 \\ 0 & \text{if } C^2(n_k,t) = 1 \\ \left[\dfrac{P'(n_k,t,\Delta t)}{\log(|N_i(t)|)}\right] & \text{otherwise} \end{cases}$$

Here, $N_i(t)$ is the set of neighbors of n_i at time t.
$P'(n_k,t,\Delta t) = -P(n_k,t,\Delta t) \log(P(n_k,t,\Delta t))$
$$P(n_k,t,\Delta t)) = (v_{avg}(i,k)) / (\sum_{n_j \in N_i(t)} v_{avg}(i,j))$$
$0<\rho<1$ and $\rho| N_i(t)|$ indicates number of neighbors of n_i outside the most recently determined AC zone.
$C^1(n_k,t) = 1$ if n_k is between left/right/top/bottom boundaries of most recently determined zone at time t and the geocast region or on the boundaries of AC zone.
$C^2(n_k,t) = 1$ if n_k is within the geocast region.
It is quite sensible to assign comparatively higher weightage to movements on the most recently decided periphery of AC zone or towards (not within) the geocast region, to restrict the growth of AC zone. Entropy of a hop from n_i to n_j between time intervals of t and t+Δt is denoted as (4).

$$H^*_{ij}(t+\Delta t) = \begin{cases} (H^*_i(t+\Delta t) \,.\, H^*_j(t+\Delta t))^{0.5} & \text{if } C_i = 1 \\ H^*_j(t+\Delta t) & \text{otherwise} \end{cases} \quad (4)$$

$C_i = 1$ if clockwise traversal around AC zone begins at n_i.
H^*_{ij} also lies between 0 and 1 for all n_i and n_j. Higher entropy improves success of multicast delivery.

4. Link Strength – This particular parameter describes the strength of a wireless channel in presence of signal attenuation and path loss. Consider, at any point of time, node n_i transmits a signal with power $p_s(i)$ and n_j receives it with power $p_r(j)$. The signal attenuation β_{ij} in dB is given by

$$\beta_{ij} = 10 \log 10 \left[\frac{p_s(i)}{p_r(j)} \right] \text{ dB} \quad (5)$$

Node n_j receives the signal of n_i properly, only if $p_r(i)$ is greater than or equal to some threshold power $p_{r,th}(j)$, denoted as receiver sensitivity. The threshold attenuation $\beta_{ij}(th)$ between the same pair of nodes is defined as follows.

$$\beta_{ij}(th) = 10 \log 10 \left[\frac{p_s(i)}{p_{r,th}(j)} \right] \text{ dB} \quad (6)$$

Link strength $L^*_{ij}(t)$ is defined as (7).

$$L^*_{ij}(t)=1-\beta_{ij}/\beta_{ij}(th) \quad (7)$$

It may please be noted that $0\leq L^*_{ij}(t) \leq 1$. Values closer to 1 indicate high immunity against attenuation.

5. Neighbor Update Interval – A node periodically broadcasts “HELLO” message within it’s radio range which is immediately processed by it’s neighbors. By the term “Neighbor Update Interval” of a node, we mean the relative interval between two consecutive transmissions of “HELLO” message by that node w.r.t. the minimum and maximum neighbor update intervals available in the network. It is denoted as U* and defined as follows:

$$U^*(i) = (\tau'_i - \tau'_n) / (\tau'_m - \tau'_n) \quad (8)$$

where τ'_i is the interval between consecutive transmission of n_i. τ'_n and τ'_m indicate network wide minimum and maximum value of τ'. As per the definition in (8), U* lies between 0 and 1. Higher the value of U*, lesser will be the possibility that it will fail to alert an unaware multicast member.

Reliability of a hop from n_i to n_j, on an edge of initial AC zone is computed at n_i and all required parameters of n_j i.e. radio-range, power of received signal, receiver sensitivity, neighbor-update interval, velocity statistics and maximum velocity of the receiver, are embedded within the alert message.

It may please be noted that all of the above mentioned parameters are equally important for estimation of initial size of AC zone. So, before designing the fuzzy rule bases, crisp ranges (uniform width) of all the above mentioned parameters are defined together in table 1.

TABLE 1: MAPPING CRISP RANGES OF PARAMETERS TO FUZZY VARIABLES

Crisp Ranges of Parameters	Fuzzy Variables
0 – 0.25	a
0.25 – 0.50	b
0.50 – 0.75	c
0.75 – 1.00	d

Fuzzy composition of radio proportion γ* and proximity P* are shown in table 2, which produces first intermediate output temp1. Table3 combines temp1 and link strength L* to produce temp2 as output. temp2 is integrated with H* in table 4 generating another temporary output temp3, which is combined with neighbor update interval U*, in table 5 to produce reliability. Upper bound of distance between the source node and any peripheral vertex of AC zone is given by $h.R_m$, where h is maximum allowable hop count [21] in the network and R_m denotes maximum available radio range.

TABLE 2: PRODUCING temp1

γ* → P* ↓	a	b	c	d
a	a	a	b	c
b	a	b	b	c
c	b	b	c	d
d	c	c	d	d

TABLE 3: PRODUCING temp2

temp1 → H* ↓	a	b	c	d
a	a	b	b	c
b	a	b	c	d
c	b	c	c	d
d	c	d	d	d

TABLE 4: PRODUCING temp3

temp2 → L* ↓	a	b	c	d
a	a	b	b	c
b	a	b	c	d
c	b	c	c	d
d	c	d	d	d

TABLE 5: PRODUCING reliability

temp3 → U* ↓	a	b	c	d
a	a	b	b	c
b	a	b	c	d
c	a	b	c	d
d	b	c	d	d

E. Shape And Size Correction Of AC zone

Preliminary structural arrangement of AC zone, as described in the previous subsection, is applicable only for the first message packet. Later on, according to the information about velocity and current position (X and Y coordinates) of a multicast member, shape and size of the AC zone can be corrected. This greatly reduces the size of AC zone as well as transmission cost for subsequent message packets. According to the Random Way Point (RWP) Mobility Model in [21], a non-uniform continuous speed distribution ζ bounded by v_{min} and v_{max} can be expressed in terms of a β distribution in (9).

$$\zeta(v) = \frac{(v - v_{min})^{\mu_1 - 1} (v_{max} - v)^{\mu_2 - 1}}{B(\mu_1, \mu_2) (v_{max} - v_{min})^{\mu_1 + \mu_2 - 1}} \quad (9)$$

The beta function is defined by $\int_0^1 z^{\mu_1 - 1} (1-z)^{\mu_2 - 1} dz$ [25, 26].

Depending upon values of non-zero parameters $\mu_1$and μ_2, the function ζ can take a variety of shapes [21]. For eg., if $\mu_1 > 1$ and $\mu_2 > 1$, it has a concave down shape. If $\mu_1 = \mu_2$, the curve is symmetric around $(v_{max} - v_{min})/2$. Otherwise the maximum or minimum is closer to v_{max} or v_{min} [21]. For $\mu_1 = \mu_2 = 1$, a uniform distribution is obtained. The average speed for this beta distribution is given by $(\mu_1 v_{max} + \mu_2 v_{min}) / (\mu_1 + \mu_2)$. Example plots of the beta distribution, for instance, can be found in [21,22]. The expected velocity transition time $E_v(t)$ is expressed as (10).

$$E_v(t) = E(L) \int_{v_{min}}^{v_{max}} \zeta(v) / v \quad dv \quad (10)$$

where E(L) indicates the expected transition length (Euclidean distance that a node travels during one movement period between two way points [21]) whose mathematical expression can be found in (11).

$$E(L) = \varpi(s'_x, s'_y) / 15 + \omega(s'_x, s'_y) / 6 \quad (11)$$

where,

$$\varpi(s'_x, s'_y) = (s'^3_x/s'^2_y + s'^3_y/s'^2_x + \sqrt{(s'^2_x + s'^2_y)}\Upsilon(s'_x, s'_y))$$

$$\Upsilon(s'_x, s'_y) = 3 - s'^2_x/s'^2_y - s'^2_y/s'^2_x$$

$$\omega(s'_x, s'_y) = (s'^2_y/s'_x f_1(s'_x, s'_y) + s'^2_x/s'_y f_2(s'_x, s'_y))$$

$$f_1(s'_x, s'_y) = \text{arcosh}(\sqrt{(s'^2_x + s'^2_y)} / s'_y)$$

$$f_2(s'_x, s'_y) = \text{arcosh}(\sqrt{(s'^2_x + s'^2_y)} / s'_x$$

$$\text{arcosh}(x) = \ln(x + \sqrt{(x^2 - 1)})$$

s'_x and s'_y indicate maximum possible x and y coordinate of the network, respectively. Let, in one particular multicast communication session, the multicast members are $n_1, n_2, n_3, \ldots, n_m$. For $1 \leq i \leq m$, assume the followings:

- n_i receives j-1 (j > 1) th packet of a multicast message at time t_l
- coordinate of n_i at time t_l is (x_i^l, y_i^l) and the same of source is (x_s^l, y_s^l)
- velocity of n_i at time t_l is v_i^l and expected velocity transition time is $e_t(i, l)$
- maximum velocity of n_i is denoted as $v_{max}(i)$
- Source receives acknowledgement of j-1 th packet from n_i by time t_i and from all other multicast members by time t_κ. Now it is ready to transmit the j th multicast packet and hence,

coordinate of peripheral vertices of AC zone need to be determined anew. Velocity of a node n_i at this point of time is v_i^κ and the same of geocast signal is v_s.

If $t_i \geq t_l + e_t(i, l)$, it is highly expected that by the time source receives acknowledgement of j-1 th packet, velocity of n_i has been drifted from v_i^1. In order to circumscribe all possible positions of n_i, v_i^κ is set to $v_{max}(i)$. Actual location of n_i till the arrival of next packet of multicast message is then bounded by a circle with center (x_i^1, y_i^1) and radius $v_i^\kappa(t_i-t_l+t')$ such that,

$t'(v_s - v_i^\kappa) = \sqrt{((x_i^1 - x_s^1)^2+(y_i^1 - y_s^1)^2)}$

i.e. $t' = \sqrt{((x_i^1 - x_s^1)^2+(y_i^1 - y_s^1)^2)} / (v_s - v_i^\kappa)$

This is based on the fact that, distance to be covered by the geocast signal after transmission of j th packet, must be equal to the maximum distance which may be covered by n_i till arrival of the j th message packet. These circular territories after being projected onto the multicast region may (fully/ partly) or may not overlap. AC zone is collectively formed by portions of these projected partly overlapped (if any) circular tessellations and portions of conical regions (excluding the geocast region in both cases) bounded by circular tessellations along with associated slanting tangential surface from source node onto those circles. The situation is represented in figures 6a and 6b. However it may please be noted that current geocast message packet is forwarded not only to the geocast region but to the present (corrected) AC zone also.

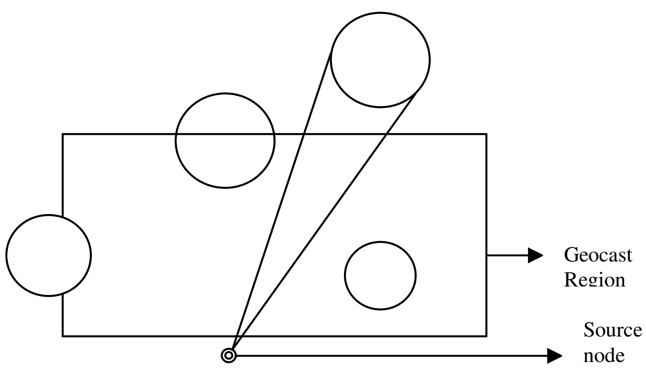

Fig. 6a.Shape & size correction of AC zone

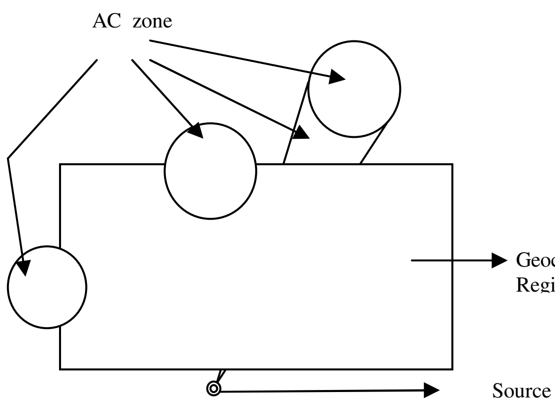

Fig. 6b. Corrected AC zone

This shape and size correction treatment, greatly reduces the area of AC zone maintaining high throughput (message delivery rate) because minimum and maximum velocity of individual nodes are taken into consideration rather than universal minimum and maximum. Indirectly, it ensures optimal network throughput at optimal cost, i.e. number of messages.

F. Adaptive Communication Procedure

Before beginning the geocast operation, "alert" message is transmitted during determination of initial shape of AC zone. Format of the message is as follows:

s	m	s~	x_1	y_1	x_2	y_2	t~	k~

where s and m denote the source and message identifier respectively. s~ is sequence number of the packet in current multicast message with identifier m. (x_1, y_1) and (x_2, y_2) indicate bottom-left and top-right corners of geocast region, in that order. Time of initiating multicast message is t~; k~ is the number of packets in the multicast message; obviously, 0<s~<k~. Source node begins transmission of the actual geocast message immediately after completion of clockwise traversal around the geocast region . As soon as a node receives the multicast message, it determines whether it was within the geocast region when the operation was initiated by the sender. If, at that time the node was within the geocast region, then by default it is a multicast member. All multicast members receive the geocast message and acknowledges it, while others discard the same.

A multicast message consists of all fields in "alert" message along with the actual message information string and AC zone specification(except for the first message packet). A node within preliminary AC zone always concatenates the alert message (first information message packet) with HELLO communiqué for detection of neighbors in the direction towards the geocast region, till first information message packet arrives (or message queue overflows) before it leaves preliminary AC zone. Actually AC zone specification is a variable length record of triples – center of the AC zonal component circle(s) (as per figs. 6a & 6b) and two intersection points of any arbitrary zonal component circle with an edge or edges of the geocast region. Three such triples will be there corresponding to figures 6a and 6b . Format of the acknowledgement message is as follows:

d	m	s′	x_i	y_i	v_{min}	v_{max}

Here d and m indicate destination identifier and message identifier respectively. s′ is serial index of the packet received. (x_i, y_i) symbolize present Euclidean coordinate position of the receiver. v_{min} and v_{max} denote minimum and maximum velocity of the respective destination (with d being the identifier) in that order. It may please be noted that, a node, instead of explicitly storing all previous positions, stores current velocity, direction of movement, timestamp of the present record, latitude-longitudinal position from where the new velocity record begins to be effective. In this context we have assumed that, a node moves with uniform velocity between interval of timestamps of two consecutive records. A new record is appended to the velocity database above, provided any one of first two fields of information of the new record, differ from the same of so far last record (most recent) in the database.

Utilizing these records, position of a node at a given point of time can be easily computed from velocity laws of Newton. Also, space complexity is greatly reduced by this mechanism. Since records are stored in increasing order of timestamps (obviously), position of a node at a given point of time can be calculated applying binary search technique on velocity database with timestamp of initiation of geocast as key.

Block diagram of the adaptive geocast communication procedure from point of view of the source node, multicast members, non-member nodes in AC zone are presented in figures 7a, 7b and 7c respectively. If the "multicast" or "alert" message reaches to some node in the network not belonging to these three categories (source, member, non-member in AC zone) it automatically discards the packet.

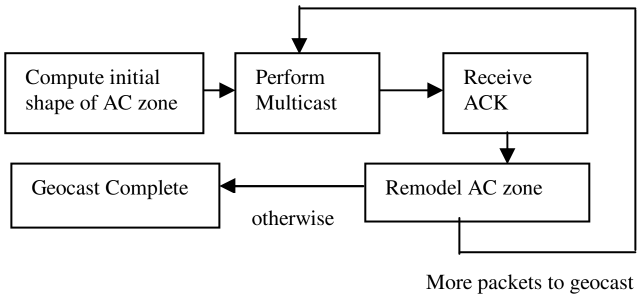

Fig. 7a. Adaptive geocasting by source

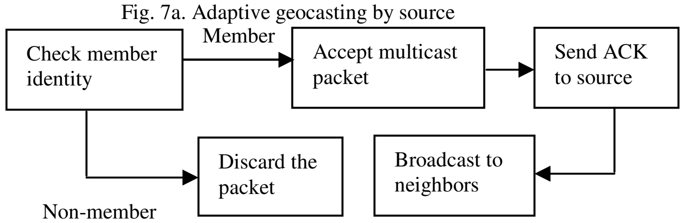

Fig 7b. Adaptive geocasting by geocast members and non-members (not in AC zone)

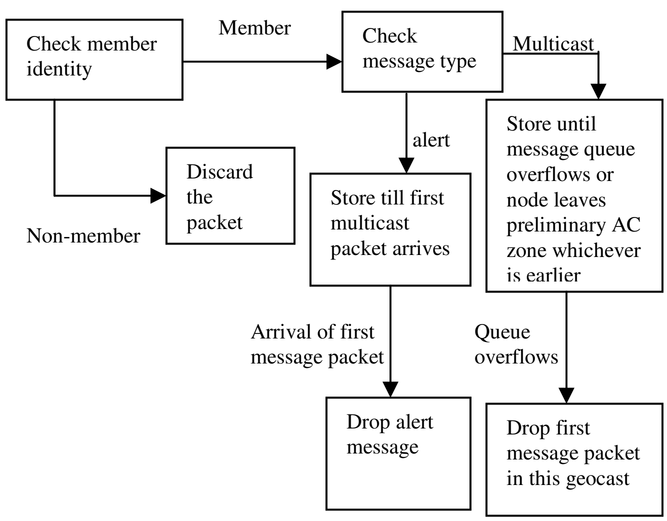

Fig 7c. Adaptive geocasting by non-members in AC zone

III. PERFORMANCE ANALYSIS

Following propositions present a rigorous mathematical analysis of performance of adaptive geocasting scheme in comparison to other location based multicast communication algorithms like location based multicast schemes 1 & 2 [7] and multicast flooding [8,14] proposed earlier. It has already been proved that location based multicast schemes 1 and 2 [7] are far more acceptable than multicast flooding as far as the tradeoff between success rate of delivery and message cost in the context of geocast operation is concerned. Adaptive geocasting is capable of producing excellent success rate of message delivery, almost equivalent to the same produced by multicast flooding at a much lesser cost almost equivalent to the same suffered by location based multicast schemes in [7]. As node density in the network increases, relevance of adaptive geocasting grows.

Proposition 1:
As far as the success rate of geocast message delivery is concerned, performance enhancement of our adaptive geocasting scheme w.r.t. location based multicast schemes 1 & 2 in reference [7], exponentially increases as N, the number of nodes in the network, increases linearly.

Proof:
The merit of our adaptive geocasting scheme relative to location based multicast schemes 1 & 2 in [24], lies in the fact that we specially consider the nodes which stay in the "region of vulnerability" or RV (see definition 1) during the time the multicast operation was initiated.

Definition 1: Region of Vulnerability (RV)
Region of vulnerability or RV denotes such a closed portion of geocast region, from where a node may move out of the geocast range with network wide maximum velocity, without receiving the message. For example, the rectangular geocast region in fig. 8a, contains RV shown in fig. 8b. However, it may please be noted that geocast region can be of any shape and size. For simplicity, we have taken a rectangular geocast region as example which will be generalized later in this section.

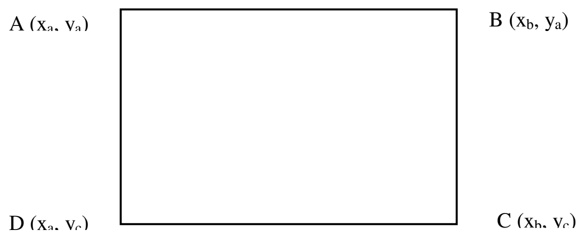

Fig. 8a. Geocast Region Specification

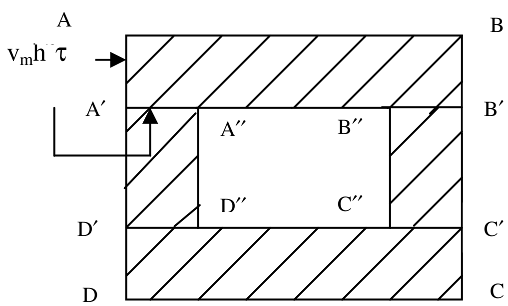

Fig. 8b. RV Specification (v_m, $h^{\sim}$ and τ carry their usual meaning)

In fig. 8b, RV consists of four rectangular tessellations, ABB′A′, CDD′C′, A′A″D″D′ and B′B″C″C′.

Lemma1:
Perpendicular distance between top (similarly for bottom, left, right) boundaries of geocast region and RV, is either 0 or $v_m h^{\sim} \tau$ where v_m is the network wide maximum velocity and $h^{\sim}$ is approximated hop count corresponding to the distance between source node and farthest vertex of geocast region; τ, the average time required for transmission or forwarding a message between consecutive nodes in a communication path, is defined as

$$\tau = \left[\sum_{i=1}^{|\aleph|} m_i R_i \Big/ \sum_{i=1}^{|\aleph|} m_i \right] \qquad \nu_s$$

Here we have assumed that $\aleph$ indicates all possible categories of radio-ranges available in the network and there are m_i number of nodes with radio range R_i. ν_s is approximate speed of the wireless signal.

Proof:
Our analysis on computation of coordinates of RV is based on the following assumptions:

- In fig. 8b, RV consists of four rectangular tessellations ABB′A′, CDD′C′, A′A″D′D″ and B′B″C′C″. Let, for i-th ($1 \le i \le 4$) such rectangular tessellation, (x_l^i, y_l^i) and (x_u^i, y_u^i) indicates coordinates of bottom-left and top-right corners respectively.
- In order to compute node density before multicasting the first message packet total number of nodes N in the network is divided by the entire network area α, since total number of nodes in geocast region is unknown and it is subsequently calculated by the source node depending upon the number of acknowledgements it receives from nodes in geocast region, is given by $\wp/((x_b - x_a)(y_a - y_c))$ where $\wp$ is the exact number of multicast members as per the acknowledgement of first message packet ($\wp$ is calculated exactly once) and area of the geocast region is $((x_b - x_a)(y_a - y_c))$, according to fig. 8a.
- Weighted average of radio-ranges is R_w (as computed in this section)
- Speed of wireless signal is v_s

First we determine average progress of each hop, ς, in the network and maximum distance d^s_{max} between the source node n_s and farthest peripheral vertex of the given geocast region. Then value of expected number of hops, $h^{\sim}$, can be expressed as (12).

$$h^{\sim} = \lceil d^s_{max} / \varsigma \rceil \qquad (12)$$

The average one hop progress ς can be approximated as the average of maximum distance between a sender and each of the neighbors within it's transmission range. Note that, it is only an approximation which assumes that the farthest neighbor from the sender is always in the direction towards the geocast region. Our simulation results presented in section V, show that this approximation works quite well. Approximately, average number of nodes ψ in the geocast region, is given by expression (13).

$$\psi = \begin{cases} (N/\alpha)\pi R^2_w & \text{if current packet is first by sequence} \\ (\wp/((x_b - x_a)(y_a - y_c)))\,\pi R^2_w & \text{otherwise} \end{cases} \qquad (13)$$

Assuming uniform node distribution in the network, the probability F(r) of all ψ nodes residing within distance r from center of the transmission circle of radius R_w, is given by (14). F(r) = Prob (All ψ nodes reside in a circle of radius r)

i.e.F(r) = [Prob(a node stays in a circle of radius r)]$^{\psi}$

i.e. $F(r) = [\pi r^2 / \pi R^2_w]^{\psi}$

i.e. $F(r) = r^{2\psi}/R^{2\psi}_w \qquad (14)$

The average progress probability density function (pdf) of f(r) progress r from source, is as follows:

$$f(r) = \frac{\partial}{\partial r} F(r) = 2\psi \frac{r^{2\psi - 1}}{R^{2\psi}_w}$$

The average progress ς is then the expected value of r with respect to pdf f(r) as given by (15).

$$\varsigma = \int_0^{R_w} r\, f(r)\, dr = \frac{2\psi R_w}{2\psi + 1} \qquad (15)$$

Based on (12): when $\psi = 0$, $\varsigma = 0$ i.e. no progress can be achieved; when $\psi = 1$, $\varsigma = 2R_w/3$; for larger values of ψ, the progress approaches R_w. Without any loss of generality, if we assume that vertex B of geocast region in fig. 2 is farthest from source node, say n_s, maximum possible distance between source and farthest multicast member is as follows:

$$d^s_{max} = \sqrt{((x_b - x_s)^2 + (y_a - y_s)^2)}$$

Therefore, expected number of hops $h^{\sim}$, can be estimated as expression (13).

$$h^{\sim} \cong \lceil d^s_{max} / \varsigma \rceil \cong \lceil d^s_{max}(2\lfloor\psi\rfloor + 1)/(2\lfloor\psi\rfloor R_w) \rceil \quad (16)$$

By the time a message reaches from source to farthest destination geocast member residing within the geocast region at the time of arrival of multicast message, a member with network wide maximum speed, will be able to traverse a distance of $v_m h^{\sim}\tau$, in any arbitrary direction. Hence, we can conclude the followings:

coordinates of bottom-left and top-right corners, respectively. Hence, we conclude the followings.

$x_l^1 = x_a \quad y_l^1 = y_a - v_m h^{\sim}\tau$
$x_u^1 = x_b \quad y_u^1 = y_a$
$x_l^2 = x_a \quad y_l^2 = y_c$
$x_u^2 = x_b \quad y_u^2 = y_c + v_m h^{\sim}\tau$

$x_l^3 = x_a \quad y_l^3 = y_c + v_m h^{\sim}\tau$
$x_u^3 = x_a + v_m h^{\sim}\tau \quad y_u^3 = y_a - v_m h^{\sim}\tau$
$x_l^4 = x_a - v_m h^{\sim}\tau \quad y_l^4 = y_c + v_m h^{\sim}\tau$
$x_u^4 = x_b \quad y_u^4 = y_a - v_m h^{\sim}\tau$

The above mentioned values of x_l^i, x_u^i, y_l^i, y_u^i $(1 \le i \le 4)$ are applicable only when both $x_b - x_a$ and $y_a - y_c$ are greater than $2v_m h^{\sim}\tau$, else, the whole geocast region becomes RV. For the later situation, assume that, (x_l, y_l) and (x_u, y_u) denote the coordinates of bottom-left and top right corners of geocast region. Then, obviously, $x_l = x_a$, $y_l = y_c$, $x_u = x_b$ and $y_u = y_a$.

Lemma2:

Irrespective of whether RV encompasses whole geocast region or is disintegrated into four components, (x (and y) coordinate of top right corner of RV – x (and y) coordinate of bottom left corner of RV) > 0, i.e., $x_u - x_l$, $y_u - y_l > 0$ or $x_u^i - x_l^i$, $y_u^i - y_l^i > 0$ $(1 \le i \le 4)$.

Proof:

Case -1:
RV is the geocast region itself. Hence, $x_u - x_l = x_b - x_a > 0$ (by default) and $y_u - y_l = y_a - y_c > 0$ (by default). This satisfies our requirement for case - 1.
Case -2:
RV is divided into four distinct components. So, it is given that, $y_a - y_c > 2v_m h^{\sim}\tau$ (17)

1. $x_u^1 - x_l^1 = x_b - x_a > 0$ (by default) ,
   $y_u^1 - y_l^1 = v_m h^{\sim}\tau > 0$ $(v_m, h^{\sim}, \tau > 0)$
2. $x_u^2 - x_l^2 = x_b - x_a > 0$ (by default), $y_u^2 - y_l^2 = v_m h^{\sim}\tau > 0$
   $(v_m, h^{\sim}, \tau > 0)$
3. $x_u^3 - x_l^3 = v_m h^{\sim}\tau > 0$, $y_u^3 - y_l^3 = y_a - y_c - 2v_m h^{\sim}\tau > 0$
   (from 17)
4. $x_u^4 - x_l^4 = v_m h^{\sim}\tau > 0$, $y_u^4 - y_l^4 = y_a - y_c - 2v_m h^{\sim}\tau > 0$ (from 14)

So, it is proved that $x_u^i - x_l^i > 0$, $y_u^i - y_l^i > 0$ $(1 \le i \le 4)$

€

For a network deployed in a bounded system area, let the random variable Ω = (X, Y) indicate the Cartesian location of a mobile node in the network at an arbitrary time instant. The spatial distribution of a node is expressed in terms of a probability density function ρ s.t.

$$\rho = \lim_{\delta \to 0} \frac{\Pr[A \wedge B]}{\delta^2}$$

where A is the event when $(x - \delta/2) < X \le (x + \delta/2)$
B is the event when $(y - \delta/2) < Y \le (y + \delta/2)$
The probability that a given node is located within sub area (RV) α′ of the system area α can be computed by integrating ρ over the region of vulnerability.

$$\Pr[\text{a node in } \alpha'] = \Pr[(X,Y) \in \alpha'] = \iint_{\alpha'} f_{XY}(x, y)\, d\alpha \quad (18)$$

where $f_{XY}(x, y)$ can be computed by stochastic analysis of any arbitrary mobility model. The expression (18) is universally applicable to any kind of mobility pattern; ρ can be obtained from related stochastic analysis. Given this ρ, we treat it as a mobile nodes arrival rate of each standing position. According to the model (based on spatial Poisson Point Process) of random presence of mobile nodes in [30], The probability that there are exactly ξ nodes in RV of area α′ (N is total number of nodes in the network), following a uniform distribution model, can be seen in (19).

$$\Pr[\eta = \xi] = \frac{(N\rho \,.\, \alpha')^{\xi}}{\xi!} \varepsilon^{-N\rho \cdot \alpha'} \quad (19)$$

The same corresponding to a non-uniform distribution model is given by (20).

$$\Pr[\eta = \xi] = \iint_{\alpha 1} (N\rho\ \alpha')^{\xi} / \xi!)\, \varepsilon^{-N\rho}\, d\alpha \quad (20)$$

So, according to [22], probability that RV is empty under uniform distribution model, is as follows:
$\Pr[\eta=0] = \varepsilon^{-N\rho\alpha'} = O(\varepsilon^{-N\rho})$ (since $\alpha' >> 0$) (21)

From [22, 24, 25], similar probability under non-uniform distribution model is given by (22).

$$\Pr[\eta = 0] = \iint_{\alpha'} \varepsilon^{-N\rho}\, d\alpha \quad (22)$$

Since RV of area α′ is disintegrated into four components, then

$$\iint_{\alpha'} \varepsilon^{-N\rho}\, d\alpha = \varepsilon^{-N\rho} \left[\sum_{i=1}^{4} \left\{ \int_{x_l^i}^{x_u^i} dx \int_{y_l^i}^{y_u^i} dy \right\} \right]$$

$$\text{i.e.} \iint_{\alpha'} \varepsilon^{-N\rho} d\alpha = \varepsilon^{-N\rho} \left[\sum_{i=1}^{4} (x_u^i - x_l^i)(y_u^i - y_l^i) \right] = C_1 \varepsilon^{-N\rho}$$

$C_1 > 0$ since, $(x_u^i - x_l^i)$, $(y_u^i - y_l^i) > 0$ for all $1 \le i \le 4$ (according to lemma 2)
On the other hand, if RV is the geocast region itself, then,

i.e. $\iint_{\alpha'} \varepsilon^{-N\rho} \, d\alpha = \varepsilon^{-N\rho} [(x_b - x_a)(y_a - y_c)] = C_2\varepsilon^{-N\rho}$

Also $C_2>0$ since, $x_b > x_a$ and $y_a > y_c$. So, it can be concluded that $\iint_{\alpha'} \varepsilon^{-N\rho} \, d\alpha = O(\varepsilon^{-N\rho})$

If the geocast region is not rectangular, let

- RV1 (area α1) indicates the region of vulnerability for the given geocast region
- RV2 (area α2) denotes the region of vulnerability corresponding to the largest rectangular region as area of multicast within the geocast region
- RV3 (area α3) denotes the region of vulnerability corresponding to the largest rectangular region as area of multicast surrounding the geocast region

Then, from the above discussion we can write

$$\iint_{\alpha 2}\varepsilon^{-N\rho} \, d\alpha = O(\varepsilon^{-N\rho}) \le \iint_{\alpha 1} \varepsilon^{-N\rho} \, d\alpha \le \iint_{\alpha 3} \varepsilon^{-N\rho} \, d\alpha = O(\varepsilon^{-N\rho})$$

Assume that, $\iint_{\alpha 1} \varepsilon^{-N\rho} \, d\alpha + z1 = \iint_{\alpha 3} \varepsilon^{-N\rho} \, d\alpha$ (23)

and

$\iint_{\alpha 2} \varepsilon^{-N\rho} \, d\alpha \, (=O(\varepsilon^{-N\rho}))+z2 = \iint_{\alpha 3}\varepsilon^{-N\rho} \, d\alpha \, (=O(\varepsilon^{-N\rho}))$ (24)

It is obvious that z1 <z2 because RV2 is embedded within RV3. From (24) we get, $z2 = O(\varepsilon^{-N\rho})$. Since z1<z2, so, $z1=O(\varepsilon^{-N\rho})$. Applying this in (23) we arrive at (25).

$\iint_{\alpha 1} \varepsilon^{-N\rho} d\alpha + O(\varepsilon^{-N\rho}) = \iint_{\alpha 3} \varepsilon^{-N\rho} \, d\alpha \, (= O(\varepsilon^{-N\rho}))$ (25)

So, $\iint_{\alpha 1} \varepsilon^{-N\rho} d\alpha = O(\varepsilon^{-N\rho})$ (26)

The above expression emphatically justifies the merit of adaptive geocasting.

□

Proposition 2:

Probability of successful geocast delivery exponentially approaches 1 as the total number of nodes in AC zone (M) and geocast region (z) increases linearly.

Proof:

Let, n_i be a multicast member and before it leaves the geocast region to enter into AC zone, ιz (ι ≤ 1) number of nodes in geocast region has received the message. The event ν′ that n_i will remain unaware of the geocast transmission will take place only if it's set of neighbors does not contain any of those ιz multicast members and M number of non-members ("with alert message") in AC zone, throughout it's journey (say, α~ indicates it's traversed area) from geocast region to outside network. According to [22, 24], probability of ν′ is as follows.

$$Pr[\nu'] = \iint_{\alpha 1} \varepsilon^{-\rho(M+\iota z)} \, d\alpha = O(\varepsilon^{-\rho(M+\iota z)}) = O(\varepsilon^{-\rho(M+z)})$$

i.e. Probability of successful delivery =1-Pr[ν′] i.e. $1 - O(\varepsilon^{-\rho(M+z)})$

□

IV. Performance Evaluation

To evaluate our schemes, we performed simulations using modified version of a network simulator, MaRS (Maryland Routing Simulator). MaRS [23] is a discrete-event simulator built to provide a flexible platform for the evaluation and comparison of network algorithms. Four protocols were stimulated – location-based multicast schemes 1 and 2, multicast flooding and adaptive geocasting. We studied several cases by varying the size of geocast regions.

A. Simulation Model

In eight different simulation runs, the number of nodes in the network was chosen to be 20, 50, 100, 150, 200, 300, 400 and 500. The nodes in the mobile ad hoc network are confined to a 1000×1000 square units. Initial locations (X and Y coordinates) of the nodes are obtained using a uniform distribution. We assume that a node always knows it's current position. Minimum and maximum velocity of any arbitrary node in the network, are assumed to be 0 and 10 units/ sec respectively. Each node makes several moves during the simulation and a node may pause between two moves. Two mobile nodes are considered disconnected if they are outside the radio range of one another. Different nodes may have different transmission ranges. For simulation purpose, transmission range values of 50, 75, 100, 200 and 250 are used. All wireless links have the same bandwidth of 100 kbytes/ sec. Each run simulated 1000 records of execution. A sender node is chosen randomly, whereas the geocast region is predefined. We have repeated our geocast experiment for four different shapes and sizes of geocast region – rectangle, circle, convex polygon and concave polygon. The source performs one multicast per second, which means thousands multicasts were done in each simulation run. It may be noted that here we do not model the delays that may be introduced when multiple nodes attempt to transmit simultaneously.

B. Simulation Results

In the following, the term "geocast packets" is used to refer to the 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 it's neighbors. We measure the following two parameters here:

- Accuracy of Multicast Delivery: It is calculated as the ratio of multicast group members which actually receive the packet and the number of group members which were supposed to receive the packet (i.e. number of nodes which were in the geocast region when the geocast operation was initiated.) In our simulation results, the accuracy of multicast delivery is an average over 1000 multicasts.
- Total Number of Geocast Packets Received by Nodes per Geocast: This is defined as the total number of geocast packets delivered to all the nodes combined, during each geocast. Note that when a node broadcasts a packet to it's neighbors, the packet is delivered to all it's neighbors (and counted as many times in this statistics.) The number of geocast packets received by the nodes is a measure of overhead of geocast message delivery.

We compare the results of adaptive geocasting with those from location-based multicast schemes 1 & 2 and multicast flooding, in figures 9, 10, 11, 12, 13, 14, 15 and 16 for many different shapes of geocast region.. It may be noted from figures 9, 10, 11 and 12 that for different shapes of geocast regions, accuracy of data delivery associated to adaptive geocasting, is almost same as that to multicast flooding and much higher than location based multicast schemes1 & 2 (percentage of improvement, on average, is 33.33%).
This is obvious that multicast flooding will have to bear higher message costs than location based multicast schemes [24] and adaptive geocasting. But for adaptive geocasting, message cost sometimes may even be lesser than location based multicast schemes (depending upon arbitrarily decided size of forwarding zone [24]). Figures 13, 14, 15 and 16 successfully demonstrate that, on an average, multicast flooding suffers 18.57% more message overhead than adaptive geocasting. The reason is quite understandable; adaptive geocasting implements directional flooding approaches whenever required whereas multicast flooding floods data packet to all directions.

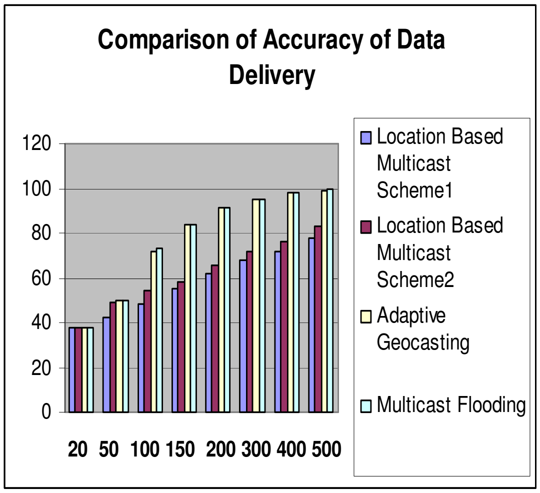

Fig. 9. Comparison of Accuracy of Delivery for Rectangular Geocast Region

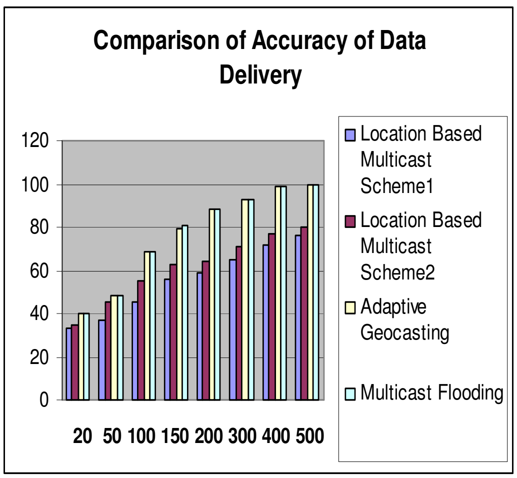

Fig. 10. Comparison of Accuracy of Delivery for Circular Geocast Region

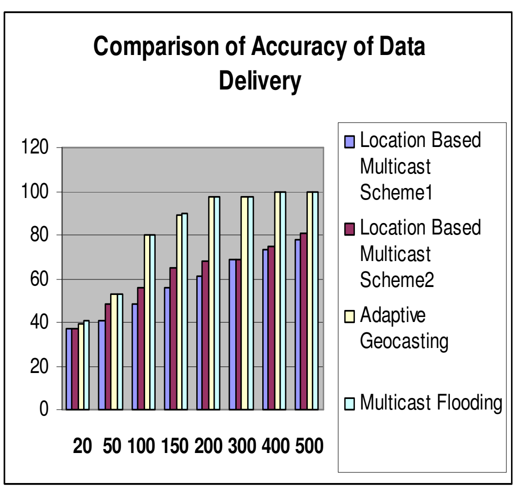

Fig. 11. Comparison of Accuracy of Delivery for Convex Geocast Region

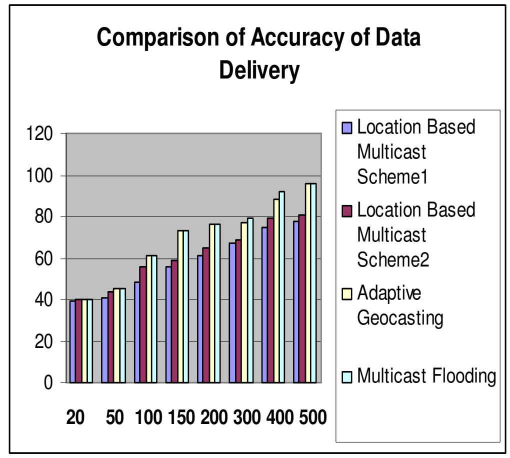

Fig. 12. Comparison of Accuracy of Delivery for Concave Polygonal Geocast Region

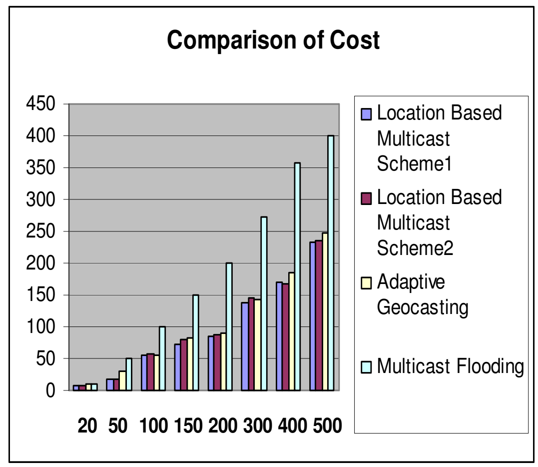

Fig. 13. Comparison of Message Cost for Rectangular Geocast Region

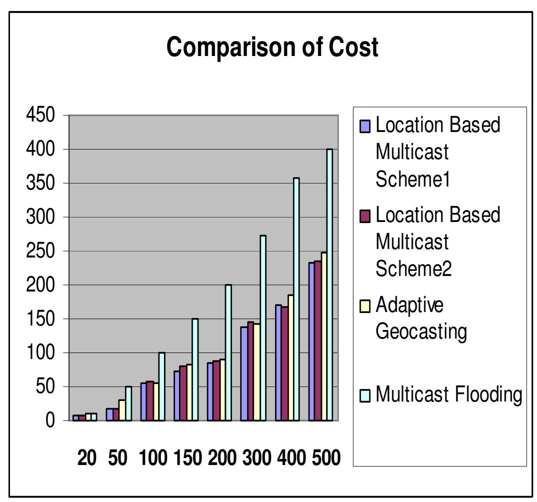

Fig. 14. Comparison of Message Cost for Circular Geocast Region

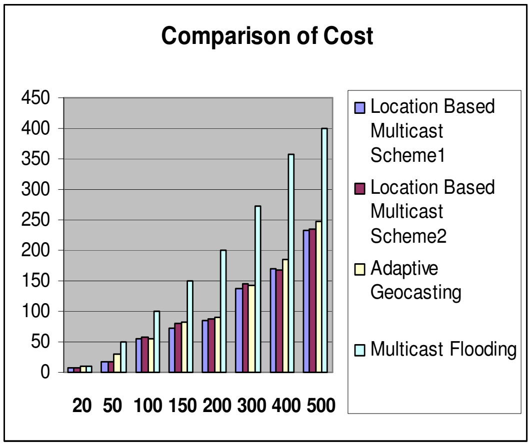

Fig. 15. Comparison of Message Cost for Convex Geocast Region

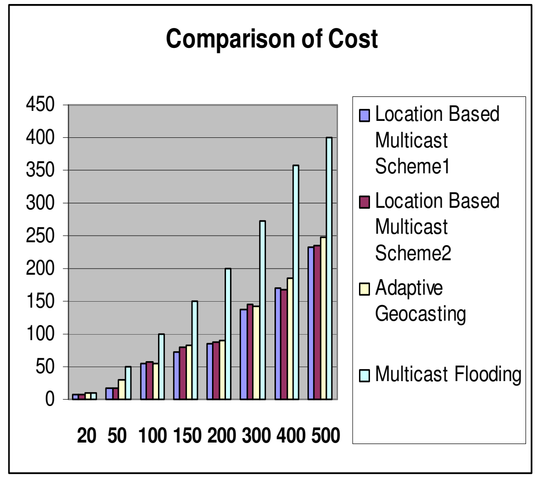

Fig. 16. Comparison of Message Cost for Concave Geocast Region

I. Conclusion

Adaptive geocasting generates excellent results, especially when node density in and the around geocast region is high. In such situations, cost of messages may be even lower than location based multicast schemes 1 and 2 proposed in reference [24], along with almost hundred percent success in message delivery like multicast flooding. Briefly we can claim that, in today's era of wireless communications, adaptive geocasting produces a huge success in message delivery at minimum possible cost.

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