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RESEARCH ARTICLE

Receiver Based Geographic Multicast Routing in Ad Hoc Networks

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Abstract— Existing multicast routing protocols uses multicast trees (or mesh) where receiving nodes maintains routing information. In sensor networks where traffic is bursty, this multicast state maintenance adds a large amount of overhead to the routing. Thus, we have developed a stateless receiver-based multicast geographic routing protocol that simply embeds list of the multicast members (e.g., sinks), in packet headers. The receivers will decide the best way to forward the multicast load. This protocol, called RBGeographicMulticast exploits the knowledge of the geographic locations of the nodes to remove the need for costly state maintenance (e.g., tree/mesh/neighbour table maintenance), making it ideally suited for Ad hoc network multicast applications.

Key Terms: - Mobile ad hoc networks; multicast regions; virtual node; location; geographic multicasting

I. Introduction

Several applications in Ad Hoc networks require data delivery to multiple destination nodes, where the use of multicast routing is an ideal approach to manage and reduce network traffic. Communication in sensor networks is hindered by the limited energy capacity of the individual sensor nodes. Consequently, reducing the total number of packets transmitted throughout the network is essential for power conservation. For sensor networks with multiple sink nodes, multicast routing is an ideal approach to manage and reduce network traffic. Reducing the number of packets transmitted when multicasting data requires both shorter routing paths from the multicast source to the multicast members, as well as improved efficiency in terms of the total number of links the packets traverse to get to all the multicast members, i.e., only if different routing branches are there the packet should be split off. Wireless sensor networks (WSNs) are dynamic due to the mobility of the nodes. Providing robust routing in such dynamic networks is an important design challenge.

In this paper, we develop a novel multicast protocol called RBGeographicMulticast. RBGeographicMulticast is a completely stateless multicast protocol, using only location information with no tree creation or maintenance or even neighbor table maintenance, which makes it ideally suited for ad hoc networks. Packet routing and duplicating packets into multiple routes relies only on the location information of each destination node, which is assumed to be known.

RBGeographicMulticast is a receiver-based protocol(like ExOR protocol[1]) which means that a sender can transmit packets without specifying the next hop node, because receiving node of the packet will decide whether to forward this packet in a distributed manner. This approach does not require routing tables and enables the use of spatiotemporal neighbourhood. This can be compared to proactive and reactive routing protocols where the route is decided using latest available information .

As in XLM [2], RBGeographicMulticast assumes a MAC protocol whereby receivers contend for channel access based on their assessed contribution towards forwarding the packet. Nodes with more energy and better links and nodes that make the most forward progress to the destination will contend earlier and hence have a higher chance to become the next-hop node. In RBGeographicMulticast, we extend this idea for multicast routing by using the concepts of a “virtual node” and a “multicast regions” for forwarding packets closer to the destination node and determining when packets should be split into separate routes to finally reach the multicast members.

We implemented RBGeographicMulticast in TinyOS and performed experiments using a Tmote Sky test-bed as well as TOSSIM simulations. Results of these experiments show that RBGeographicMulticast maintain high success rate in highly dynamic networks, where nodes only receive packets in a 10 ms interval and change radio state every 100 ms. This level of performance in such dynamic networks is not easy using other multicast approaches because nodes must keep updated information about the network. We believe that RBGeographicMulticast is lightweight and robust, making it ideally suited for multicast applications in dynamic ad hoc networks.

II. RELATED WORK

Existing multicast protocols for WSNs and mobile ad hoc networks (MANETs) generally use a tree to connect the multicast members. Additionally, multicast algorithms rely on routing tables maintained at intermediate nodes for building and maintaining the multicast tree[3].

In the location-based approach to multicast routing, nodes obtain location information by default as an application requirement (e.g., a home fire detection sensor would know where it is located) or as provided by a system module (e.g., GPS or a location-finding service). If location information is known, multicast routing is possible based solely on location information without building any external tree structure. For example, Position Based Multicasting PBM[4] weights the number of next hop neighbor nodes and total geographic distance from the current node to all destination nodes and compares this to a predefined threshold to decide whether or not the packet should be split. Geocast [5] delivers multicast packets by restricted flooding. Nodes forward multicast packets only if they are in the Forwarding Zone calculated at run time from global knowledge of location information.

But RBGeographicMulticast different from all the above approaches i.e it is completely stateless and hence no costly state maintenance is required. PBM [4] uses a similar idea of stateless multicast but requires information about neighbor nodes. RBGeographicMulticast further eliminates the requirement of knowing a node’s neighbors by using a receiver-based mechanism, and only the location of the nodes is needed for multicast packet routing. Additionally, RBGeographicMulticast includes a list of the multicast members in the packet header, which prevents the overhead of building and maintaining a multicast tree at intermediate sensor nodes, because all the necessary information for routing the packet is included within the packet header. We believe that RBGeographicMulticast requires the least state of any multicast routing protocol and is thus ideally suited for WSNs.

Receiver-based communication is a different way of thinking about protocol design in that decisions are made at the receiver side but not at the sender side. For example, a source node in “Opportunistic routing in multi-hop wireless networks” ExOR [1] broadcasts packets that include a potential forwarders’ list inside the header, and these potential forwarders will contend to forward the packet by using different times, which depend on the network distance to the destination. A source node in “A cross-layer protocol for wireless sensor networks” XLM [2] broadcasts packets with the destination’s geographic location in the header, and every receiver contends to forward the packet through the use of different back-off times, which depend on the geographic distance to the destination. But, in receiver-based routing, decision is made by the possible receivers, who make decisions in a distributed manner.

Receiver-based routing is different from “On-demand” or “Reactive” routing in that reactive routing calculates a route at the time a packet is sent down to the MAC layer. For example, AODV [6] begins transmission by first sending a “RouteRequest” to create temporary routes among intermediate nodes and then transmits data packets through this route. The ability to transmit data without requiring a route to be formed is enabled via extra knowledge in the MAC layer and join decisions of sensor nodes. For example, nodes could be assigned an ID in a structured manner and hence next hop nodes are implied in the destination address itself. In this case, packets are broadcast by the MAC layer, and only potential next-hop nodes relay it to the destination. As another example, nodes may have statistics (e.g., energy, channel quality) that could assist in making forwarding decisions. A source node can send an RTS packet, enabling potential receivers to contend for the ability to forward the packet, with the receiver node that has the best route being the first to return a CTS to receive this packet.

III. RBGEOGRAPHICMULTICAST PROTOCOL DESCRIPTION

RBGeographicMulticast is a receiver-based Network layer protocol that performs multicast routing based on receiver-based geographic unicast protocols such as XLM[2]. The receiver based unicast only needs the sender node’s location and the final destination node’s location , which are provided in the MAC packet to decide the next hop along the route. We assume that the “void” (hole) problem in geographic routing is solved implicitly using right handed rule as in GPSR[7].

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Nodes in RBGeographicMulticast create what we call "multicast regions" centered around themselves. There are several ways to create these regions (see section C.1), but for simplicity it can be assumed that each multicast region corresponds to one quadrant of the network, for a grid centered at the node, as shown in Figure 1.

When a user a try a request to send(RTS) a packet to a multicast group, data are passed down to the RBGeographicMulticast module in the Network layer of the protocol stack. Once the RBGeographicMulticast module gets this packet, it retrieves the group list from its group table, compares the group nodes' location to the multicast regions, and calculates a virtual node location for each multicast region. RBGeographicMulticast replicates the packet for each multicast region that contains one or more multicast members and appends a header consisting of a list of destination nodes (multicast members) in that region, TTL (Time to Live) value, and a checksum value. The destination of the packet is a "virtual node" for that multicast region, which can be determined in several ways(see section C.2) , but for simplicity it can be assumed to be the geometric mean of the locations of all the multicast members in the multicast region. In the end ,all packets for all multicast regions are inserted in the MAC queue, and are then broadcasted to the neighbourhood. The node closest to the virtual node will take responsibility for forwarding the packet. The algorithm for transmitting packets is given in Algorithm 1.

Algorithm 1 RBGeographicMulticast Send
Input : Packet output from upper layer
Output : Packets output to lower layer

```
Get group list N from group table
for node n in group list N do
    for multicast region r in 4 quadrants regions R do
        if n ∈ r then
            Add n into r.list
        end if
    end for
end for
for r ∈ R do
    if r.list is non-empty then
        Duplicate a new packet p
        Add RBGeographicMulticast header (TTL, checksum, r.list) to p
        insert p to lower layer
    end if
end for
```

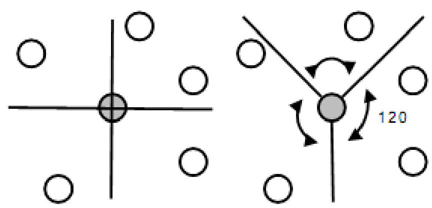
When a node receives a multicast packet, the packet is passed up from the Link layer to the RBGeographicMulticast protocol. RBGeographicMulticast first examines the checksum in the packet header, and drops the packet if any error exists in the packet. It then retrieves the destination nodes list from the RBGeographicMulticast packet header. If this node is inside the destination list, it removes itself from the list and passes a copy of the packet up to the upper layers in the protocol stack. RBGeographicMulticast then checks the TTL value and drops the packet if the TTL is lower than 0. Finally, if there still remain nodes in the destination list, multicast regions and virtual nodes will be recalculated, and new packets will be generated if required. The packets (one per multicast region that contains multicast members) are then passed down to the Link layer for transmission. The procedures for receiving packets are summarized in pseudo code in Algorithm 2.

Algorithm 2 RBGeographicMulticast Receive
Input : Packet input from lower layer
Output : Packets output to lower layer

```
Calculate checksum. Drop packet if error occur
Drop packet if not in the forwarding zone
Get destination list D from packet header
for node d in destination list D do
    if I am d then
        Duplicate the packet and input to upper layer
        Remove d from list D
    end if
end for
if TTL in header = 0 then
```

```
   Drop the packet
   return
end if
for d ∈ D do
   for multicast region r in 4 quadrants regions R do
      if d ∈ r then
         Add d into r.list
      end if
   end for
end for
for r ∈ R do
   if r.list is non-empty then
      Duplicate a new packet p
      Add RBGeographicMulticast header (TTL − 1, checksum, r.list) to p
      insert p to lower layer
   end if
end for
```

Figure 2 gives an example of how RBGeographicMulticast is employed. The first two multicast regions south-west and north-west quadrants contain only one multicast member each, and thus a packet is sent directly to these multicast destinations. The northeast multicast region has three multicast members, and thus a single packet is sent to a virtual node (with label 3 in the figure), which is located at the geometric mean of the locations of the multicast members. The southeast multicast region has no multicast members, and hence no packet is sent into this region. Once the packet sent towards virtual node 3 reaches an intermediate node for which the multicast members are no longer in the same multicast region, the node will split off packets to each of the multicast regions, using either virtual nodes if there are two or more multicast members in the multicast region or sending the packet directly to the multicast member if it is the only one in the multicast region.



(a) (b)

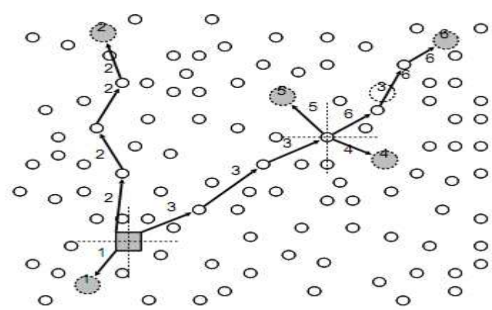


Figure 1 .a) dividing the space into four quadrants, and b) dividing the space into three 120 degree pieces

Figure 2. Example showing how RBGeographicMulticast delivers multicast packets. The source node is the square node . Multicast members are shaded circles.virtual nodes are dotted circles. Because every node will become a virtual node at the end ,they are all shown with dotted circles. The number on the side of the lines indicates the destination of the packet.

A. Multicast Regions

Once a node receives a multicast packet , it divides the network into multicast regions , and it will duplicate copy of the packet to each region that contains one or more multicast members.

We show two possible divisions of the network into multicast regions in figs 1.a and 1.b.The quadrants approach in some cases sends more packets than the 120 degree angle approach, because the multicast region decision only needs two comparisons (X and Y axes) for each multicast member and is extremely fast. We believe that it is thus preferable and apply this 4 quadrants approach in our implementation of the RBGeographicMulticast protocol. Multicast members of region divided into 4 quadrants based on the location of the virtual node. This process will continue until all multicast members are delivered packet.

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B. Virtual Node

Network layer multicast protocols, which require multiple destinations, are built on top of Link layer protocols that typically allow only a single (unicast) or all (broadcast) desti -nations. The geographic mean approach has fewer hops in general.

In RBGeographicMulticast, knowledge of neighbor nodes and routing tables are not maintained .We assign a "virtual node" located at the geographic mean of the multicast members for each multicast region. The virtual nodes (as shown in Figure 2) are not necessarily reachable or even physically exist. Even though virtual node does not exist, we can still find a next hop route using the assumed receiver-based MAC protocol to get the packet closer to the location of the virtual node. On the other hand, when using the nearest multicast node as the destination, all node addresses physically exist and virtual nodes are not necessary . The procedure to locate virtual node is described in Algorithm 4.

Algorithm 4. Virtual Node

Input: "m" multicast members of a particular regions r

Output: location of virtual node

1. **for** $n \in r$ **do**
2. $x_v=(x_1+x_2+\dots x_m.)/m$
3. $y_v=(y_1+y_2+\dots y_m.)/m$
4. **end for**
5. **return**(x_v, y_v)

C. RBGeographicMulticast Header

Figure 3 offers an example of an RBGeographicMulticast header. The first byte Protocol ID is for packet switching in the protocol stack [8]. TTL (Time To Live) provides a maximum time, in hop number, that a packet should be alive in the network. TOS (Type Of Service) indicates 4 kinds of packets in RBGeographicMulticast, which are "data", "join", "leave", and "update" packets. The update packets are used in group management and periodic group list update. DLL (Destination List Length) indicates number of nodes in the node list. The RBGeographicMulticast header size is not fixed because the destination list length is variable. Source Address is the address of the source node which is equals the RBGeographicMulticast group ID of this packet and Destination List Address stores the locations of the DLL destination nodes. The RBGeographicMulticast group ID is not actually necessary because all the multicast members are included in the header. A packet will be split off to each multicast region if multicast members exist in that region.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Protocol ID								**TTL (Time To Live)**							
TOS (Type Of Service)								**DLL (Destination List Length)**							
Checksum															
Source Address															
Destination Address 1															
:															
:															

Figure 3. RBGeographicMulticast protocol header

D. Group Management

Some nodes manage a multicast group and acts as a group head. Nodes join and leave a group by sending "join" and "leave" packets to the group head. Join and leave packets are multicast packets with destination lists that contain only the group head address. In RBGeographicMulticast every node can multicast packets to all other nodes in the same group. So the node must maintain group node lists for groups it has joined. Responsibility of the group head is to send "update" packets to all group nodes whenever some node is joining or leaving the group. Nodes send "join" packets periodically to the group head , nodes that die without sending "leave" packets are removed from the list after a time-interval.

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IV. PERFORMANCE EVALUATION

We implemented RBGM within the Global Mobile Simulation (GloMoSim) .We implemented the geographic unicast protocol GPSR which is described in[7] . In GPSR, a source. We are mainly interested in the protocol's scalability and robustness in a dynamic environment.

1) *Packet delivery ratio*: The ratio of the number of packets received and the number of packets expected to be received. For the multicast packet delivery, the ratio is equal to the total number of received packets over the multiplication of the group size and the number of originated packets.
2) *Average path length*: The average number of hops traversed by each delivered data packet.

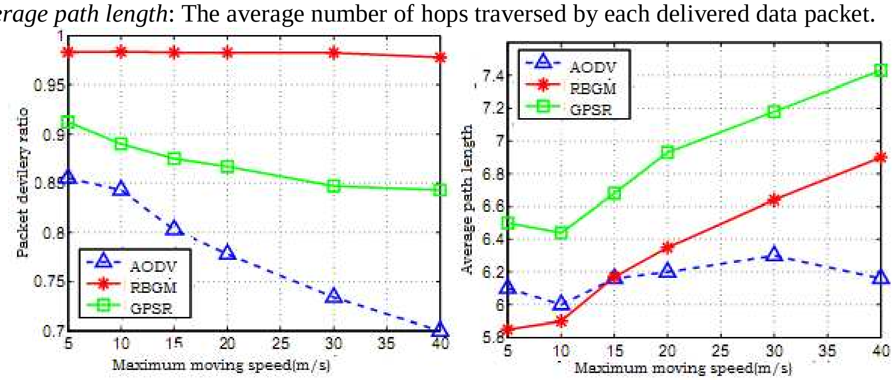

Figure 4. Performance vs. maximum moving speed (1 group, 1 source, 100 group members): (a) packet delivery ratio; (b) average path length

Impact of mobility: It is critical and challenging for a multicast routing protocol to maintain a good performance in the presence of node mobility in an ad hoc network. We evaluate the protocol performance by varying maximum moving speed from 5m/s to 40m/s.

From Fig. 4 a, in almost all the mobility cases, RBGM performs much better than AODV and GPSR. In all the mobility cases, the geographic multicast protocols RBGM and GPSR have higher delivery ratios. This is as expected, since geographic forwarding is more robust to the network topology change and both protocols use geographic unicast in their data packet transmissions to enhance reliability. RBGM keeps a stable and over 98% delivery ratio under all the mobility cases. The delivery ratios of AODV and GPSR decrease as mobility increases, and the delivery ratio of AODV drops much faster.

The average path lengths of all the protocols increase in (Fig. 4 (b)), which indicates the delivery path will become non-optimal sooner in a higher mobility environment. The mobility has more impact on the path lengths of the two geographic multicast protocols RBGM and GPSR. One reason is that the underlying geographic forwarding relies on periodic beaconing to refresh the positions of the neighbors, which cannot catch up with the changes of the neighbors' positions at a high moving speed, resulting in non-optimal forwarding decisions and longer routing paths as analyzed in work [10]. Another reason is that AODV has a shorter average end-to-end path under a higher mobility, as its pre-built paths (i.e., the mesh structure) especially those longer paths are more likely broken so packets with longer paths fail to reach their destinations. Between the two geographic multicast protocols, RBGM has a shorter path length. In RBGM, the packet forwarding from the source to a member region follows the shortest path and a detour is only introduced in the destination zone by forwarding packets first to the group leader and then to group members. In GPSR, the multicast packet forwarding follows its quad-tree structure and detours occur at multiple tree levels.

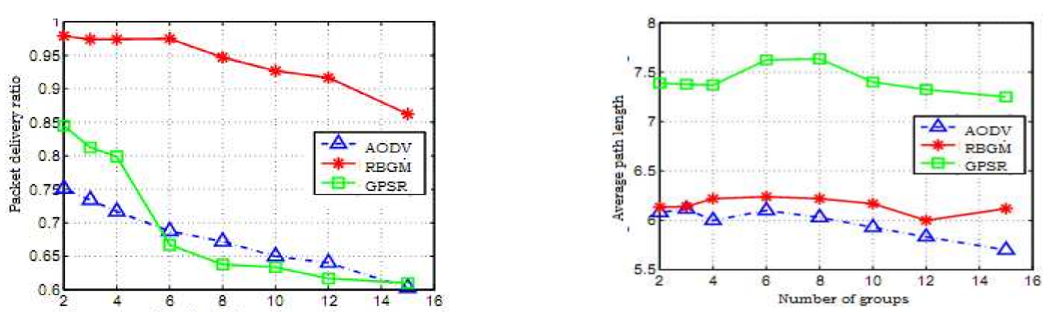

Figure 5. Performance vs. number of groups (1 source per group, totally 120 group members): (a) packet delivery ratio; (b) average path length

V. CONCLUSION

RBGeographicMulticast also utilizes a receiver-based MAC layer to further reduce the complexity of routing packets. Because we assume that the receiver-based MAC protocol can determine the next hop node in a distributed manner, the sender node does not need a routing table or a neighbor table to send packets but instead uses a "Virtual Node" as the packet destination. Thus RBGeographicMulticast requires the least amount of state of any existing multicast protocol. Our simulations and implementation of RBGeographicMulticast showed that with the Receiver-based MAC protocol XLM/MAC, RBGeographicMulticast can achieve high success rates and low latency, making RBGeographicMulticast well suited for dynamic Ad hoc network environments.

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