Efficient Multicasting in Multi-Hop Ad Hoc Networks Using Directional Antennas

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***Abstract*— Although protocols like ODMRP and MAODV do have a significant control overhead, more recent protocols like ROMANT and PUMA have reduced control overhead to a very small fraction of total overhead. Any further reduction in total overhead is possible only by a reduction in data packet overhead.**

We present the Protocol for Multicasting Over Directional Antennas (MODA) for mobile ad hoc networks (MANET). MODA is the first protocol for MANET's that uses directional antennas to reduce data packet overhead. Without increasing energy consumption, MODA increases the range of transmission as a result of which fewer nodes are involved in the forwarding process, which results in a reduction in data packet overhead. Using simulations in Qualnet 3.5, we compare MODA with PUMA and ODMRP. The results from a wide range of scenarios of varying mobility, group members, number of senders, traffic load, and number of multicast groups show that MODA attains comparable packet delivery ratios to ODMRP and PUMA, while incurring far less overhead.

***Keywords*— Ad hoc networks, routing, multicasting, multicast mesh, multicast tree.**

I. Introduction

One of the major challenges facing multicasting protocols in ad hoc networks today is the excessive data packet overhead. This problem is more acute in mesh based protocols as compared to tree based protocols. This problem principally occurs because large number of nodes which are neither interested in receiving nor sending a data packet for a particular multicast group need to transmit the packet in order to forward it from senders to receivers.

Several multicast routing protocols have been proposed for MANETs [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]. All multicast approaches proposed so far for MANETs have been based on omnidirectional transmissions of data packets.

MODA significantly reduces the overhead incurred in forwarding multicast data packets by taking advantage of the longer ranges attainable with directional transmissions for the same transmission power, and by avoiding nodes within the omnidirectional transmission range of a sender in a multicast mesh.

Depending on the configuration of the network and the location of the senders and receivers, using directional antennas can be extremely beneficial. This is illustrated in Figure 1. Nodes 7 is a sender and nodes 1, 2, 10, 15 and 16 are receivers. Using omnidirectional transmissions, all nodes other than nodes 1, 2, 15 and 16, (i.e., 12 nodes) would have to forward the packet in order for it to reach all receivers. Using directional antennas the same result can be achieved using only three transmissions (one by node 7 and two by node 10).

Determining how to align directional antennas to maximize packet-delivery ratio and minimize overhead in such networks in not an easy problem. The main challenge is that location information needs to be exchanged in such a way that (a) nodes have the location of all nodes to which they are interested in sending data packets, so that they may orient their antennas in the right direction, and (b) this information exchange results in a minimum increase in total overhead.

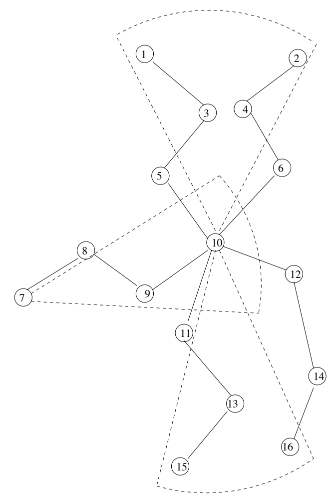

Fig. 1. Scenario where use of directional antennas is beneficial

II. MODA Description

A. Overview

Similar to assumptions made in recent prior work on directional antennas [12] [13] [14], we assume that nodes in MODA know their location through GPS and are capable of transmitting in both omni and directional mode. In our simulations we set the directional angle of transmission to 45 degrees which means that directional range of transmission is 2.45 times that of omnidirectional transmission. All nodes in MODA omnidirectionally transmit control packets which are called MODA announcements. Nodes in MODA perform a core election and the node which is closest to the center of the network is elected as core. Periodic transmission of MODA announcements allows each node in the network to learn the following: 1) address of the core b) distance (number of hops) to the core c) parent (best next-hop towards the core) and its location d) children (nodes for which this node serves as parent) and their location e) Grandparent (parent of parent) and its location f) Grandchildren (children of children) and their locations.

Receivers announce that they are tree members. Nodes which have a tree member as a child (link nodes) also become tree members, and similarly announce the fact. This results in a sequence of nodes from each receiver to the core becoming tree members. As all receivers connect to the core, this results in a tree rooted at the core. This entire process is called omnidirectional tree establishment and is similar to that in PUMA [2].

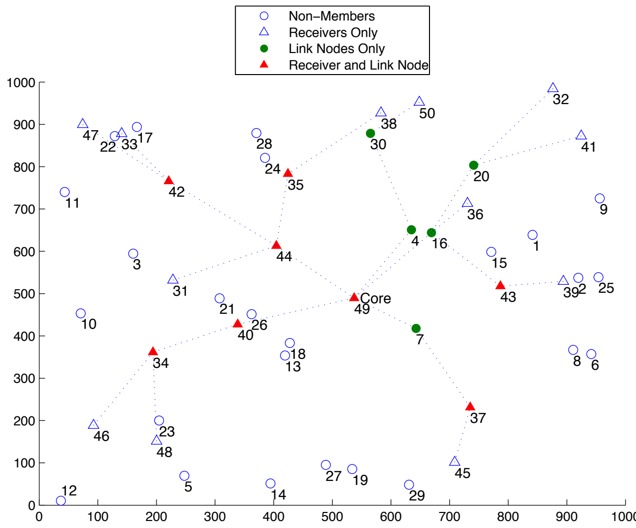

Fig. 2. Omnidirectional Tree Establishment

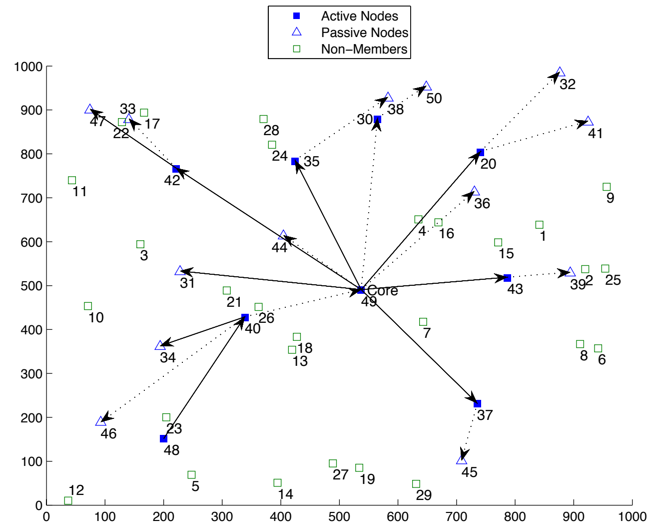

Fig. 3. Directional Data Packet Forwarding

The construction of the omnidirectional tree is illustrated in Figure 2. Node 49 is elected as the core because it is closest to the center of the network). Node 50, which is a receiver, includes node 30. Node 30 in turn includes node 4, and node 38 includes node 35, which in turn includes node 44. Similarly, all receivers include in the tree a shortest path connecting them to the core.

B. Data Packet Forwarding

In addition to using directional antennas to transmit data packets over longer distances, nodes intelligently use location information to determine which nodes have already received a data packet and hence do not need to receive it. The basic idea in forwarding a data packet in MODA is that nodes try to cover two hops instead of one while trying to forward a data packet. Each sender tries to forward a data packet towards its grandparent, till the packet reaches the core. Once a packet reaches the core each node tries to forward the packet towards its grandchildren till it reaches all receivers. In most cases when a node forwards a data packet towards it grandparent (or grandchild), its parent (or child) also receives it without having to be involved in the forwarding. Occasionally when a node has grandchildren in multiple directions, it may need to make multiple directional transmissions as one directional transmission might not reach all the grandchildren. But as the core is centrally located, simulations show that only the core needs to make multiple transmissions.

The forwarding of a data packet is illustrated in Figure 3, which shows the same network scenario as Figure 2, except that it shows transmissions between directional neighbors instead of omnidirectional neighbors. Node 48 is the source of the packet. It transmits the data packet directionally to its grandparent node 40. Node 40 does not need to transmit to node 49 because it realizes that the transmission from node 48 which it received also reached node 49. This can be determined because node 40 knows the location of node 48 and can determine the antenna pattern used to transmit. It also knows the location of node 49 based on which it knows that the transmission by node 48 also reached node 49. Node 40 transmits the packet to node 34 and not to node 46, because it realizes that the same transmission reached node 46 as well. In the figure, transmissions not carried out because the senders determined that the recipient had already received the packet are represented by dotted arrows.

Node 49 transmits the packet to it's grandchildren nodes 42, 35, 20, 43, 37 and 31. It does not transmit the packet to nodes 30, 44 and 36 because they have already received the packet in transmissions to nodes 35, 42 and 20 respectively. With the exception of node 42, none of them have to retransmit the packet because the transmissions by node 49 reach all other receivers.

III. Performance Evaluation

We compared the performance of MODA against the performance of ODMRP [4] and PUMA [2] which are representatives of the state of the art multicast routing protocols for ad hoc networks. ODMRP is a mesh-based protocol whereas PUMA has the ability to operate both as a mesh-based as well as a tree-based protocol. We operated PUMA as a tree-based protocol because we wanted to compare MODA to a tree-based as well as a mesh-based protocol.

Several experiments were carried out to determine the effect of mobility, number of senders, number of members, traffic load and number of multicast groups on the performance metrics for each protocol. The details of each experiment performed are as follows:

- Experiment 1 : Mobility varied across {0, 5, 10, 15, 20} m/s. Senders = 5, Members = 20, Traffic Load = 10 pkts/sec, Multicast groups = 1.
- Experiment 2 : Senders varied across {1, 2, 5, 10, 20}. Mobility = 5 m/s, Members = 20, Traffic Load = 10 pkts/sec, Multicast groups = 1.
- Experiment 3 : Members varied across {5, 10, 20, 30, 40}. Mobility = 5 m/s, Senders = 5, Traffic Load = 10 pkts/sec, Multicast groups = 1.
- Experiment 4 : Traffic Load varied across {1, 2, 5, 10, 25, 50} pkts/sec. Mobility = 0, Senders = 5, Members = 20, Multicast groups = 1.
- Experiment 5 : Multicast Groups varied across {1, 2, 5, 10}. Mobility = 5 m/s, Senders = 5 per group, Members = 20 per group, Traffic Load = 20 pkts/sec.

Table I indicates that the packet delivery ratio of all three protocols is quite similar. Table II indicates that the total packets transmitted by MODA is significantly below that of the other two protocols. This is because MODA's use of directional antennas results in less nodes being involved in the forwarding process.

Protocol	Mean Pkt Delivery Ratio	Std Dev
PUMA	0.90	0.08
MODA	0.88	0.08
ODMRP	0.87	0.18

TABLE I
PROTOCOL COMPARISON RESULTS FOR OVERALL PACKET-DELIVERY RATIO

Protocol	Mean Total Pkts Txed	Std Dev
PUMA	119591.14	74713.68
MODA	81191.79	49707.96
ODMRP	510246.14	296635.36

TABLE II
PROTOCOL COMPARISON RESULTS FOR TOTAL OVERHEAD

Table III specifically shows the data packet overhead incurred by the three protocols which once again illustrates the advantage of using directional antennas. Table IV shows the control overhead of the three protocols. ODMRP has the highest control overhead because each sender in ODMRP floods the network with control packets. MODA has a slightly higher control overhead that PUMA because in MODA a core election can be held once in thirty seconds if a node exists which is closer to the center of the network than the current core, whereas in PUMA it is held only when a partition occurs. However this higher control overhead is more than compensated by its lower data packet overhead as shown in Table II.

Protocol	Mean Data Pkts Txed	Std Dev
PUMA	106770.96	74626.55
MODA	66262.90	49610.22
ODMRP	233690.86	131442.41

TABLE III
PROTOCOL COMPARISON RESULTS FOR DATA PACKET OVERHEAD

Protocol	Mean Control Pkts Txed	Std Dev
PUMA	12820.18	636.86
MODA	14928.89	4438.23
ODMRP	276555.28	252413.55

TABLE IV
PROTOCOL COMPARISON RESULTS FOR CONTROL PACKET OVERHEAD

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