Multicasting in Ad-Hoc Networks: Comparing MAODV and ODMRP

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Abstract. Multicasting can efficiently support a variety of applications that are characterized by a close degree of collaboration, typical for many ad-hoc applications currently envisioned. Within the wired network, well-established routing protocols exist to offer an efficient multicasting service. As nodes become increasingly mobile, these protocols need to evolve to similarly provide an efficient service in the new environment. This paper discusses the performance of two proposed multicast protocols for ad-hoc networks: MAODV and ODMRP. MAODV builds and maintains a multicast tree based on hard state information, ODMRP maintains a mesh based on softstate. Our results show that in many scenarios ODMRP achieves a higher packet delivery ratio, but results in much higher overheads.

Motivation

Multicasting is the transmission of datagrams to a group of hosts identified by a single destination address [4]. Multicasting is intended for group-oriented computing. There are more and more applications where one-to-many dissemination is necessary. The multicast service is critical in applications characterized by the close collaboration of teams (e.g. rescue patrol, battalion, scientists, etc) with requirements for audio and video conferencing and sharing of text and images. The use of multicasting within a network has many benefits. Multicasting reduces the communication costs for applications that send the same data to multiple recipients. Instead of sending via multiple unicasts, multicasting minimizes the link bandwidth consumption, sender and router processing, and delivery delay [9].

Maintaining group membership information and building optimal multicast trees is challenging even in wired networks. However, nodes are increasingly mobile. One particularly challenging environment for multicast is a mobile ad-hoc network (MANET). A MANET consists of a dynamic collection of nodes with sometimes rapidly changing multi-hop topologies that are composed of relatively low-bandwidth wireless links. Since each node has a limited transmission range, not all messages may reach all the intended hosts. To provide communication through the whole network, a source-to-destination path could pass through several intermediate neighbour nodes. Unlike typical wireline routing protocols, ad-hoc routing protocols must address a diverse range of issues [3]. The network topology can change randomly and rapidly, at unpredictable times. Since wireless links generally have lower capacity, congestion is typically the norm rather than the exception. The majority of nodes will rely on batteries, thus routing protocols must limit the amount of control information that is passed between nodes.

The majority of applications for the MANET technology are in areas where rapid deployment and dynamic reconfiguration are necessary and the wireline network is not available [3]. These include military battlefields, emergency search and rescue sites, classrooms, and conventions where participants share information dynamically using their mobile devices. These applications lend themselves well to multicast operation. In addition, within a wireless medium, it is even more crucial to reduce the transmission overhead and power consumption. Multicasting can improve the efficiency of the wireless link when sending multiple copies of messages by exploiting the inherent broadcast property of wireless transmission. However, besides the issues for any ad-hoc routing protocol listed above, wireless mobile multicasting faces several key challenges. Multicast group members move, thus precluding the use of a fixed multicast topology. Transient loops may form during tree reconfiguration. As well, tree reconfiguration schemes should be simple to keep channel overhead low.

Many multicast routing protocols have been proposed for ad-hoc networks, a survey can be found in [7]. Comparing these protocols is typically done based on extensive simulation studies. Bagrodia et al. [1] simulated several multicast routing protocols developed specifically for MANET, some tree-based, some based on a mesh structure. The reported results show that mesh protocols performed significantly better than the tree protocols in mobile scenarios.

Lim and Kim [8] evaluated multicast tree construction and proposed two new flooding methods that can improve the performance of the classic flooding method. Royer and Perkins [11] explored the effect of the radio transmission range on the AODV protocol. They found that larger transmission ranges have many benefits (smaller trees, less frequent link breakages), but also cause more network nodes to be affected by multicast data transmission and reduce the effective bandwidth. They conclude that the transmission range should be adjusted to meet the targeted throughput while minimizing battery power consumption.

Within the MANET working group at the IETF, two proposed multicast routing protocols for ad-hoc networks are AODV[10] and ODMRP[6]. To avoid confusion with the unicast functionality of ADOV, we will refer to the multicast operation of AODV as the MAODV protocol. To date, no side-by-side comparison of MAODV and ODMRP has been done. We decided to implement these two widely discussed multicast routing protocols for ad-hoc networks in *ns-2*[5]. This simulator is publicly available and validated by frequent use, allowing others to replicate our work and/or compare their findings to our results. This paper describes the protocols and highlights our main insights.

Multicast Protocols for Mobile Ad-hoc Networks

Multicast Ad-hoc On-Demand Distance Vector Protocol

The MAODV (Multicast Ad-hoc On-Demand Distance Vector**)** routing protocol [10] discovers multicast routes on demand using a broadcast route-discovery mechanism. A mobile node originates a Route Request (RREQ) message when it wishes to join a multicast group, or when it has data to send to a multicast group but it does not have a route to that group. Only a member of the desired multicast group may respond to a join RREQ. If the RREQ is not a join request, any node with a fresh enough route (based on group sequence number) to the multicast group may respond. If an intermediate node receives a join RREQ for a multicast group of which it is not a member, or if it receives a RREQ and it does not have a route to that group, it rebroadcasts the RREQ to its neighbours.

As the RREQ is broadcast across the network, nodes set up pointers to establish the reverse route in their route tables. A node receiving a RREQ first updates its route table to record the sequence number and the next hop information for the source node. This reverse route entry may later be used to relay a response back to the source. For join RREQs, an additional entry is added to the multicast route table. This entry is not activated unless the route is selected to be part of the multicast tree. If a node receives a join RREQ for a multicast group, it may reply if it is a member for the multicast group's tree and its recorded sequence number for the multicast group is at least as great as that contained in the RREQ. The responding node updates its route and multicast route tables by placing the requesting node's next hop information in the tables, and then unicasts a Request Response (RREP) back to the source node. As nodes along the path to the source node receive the RREP, they add both a route table and a multicast route table entry for the node from which they received the RREP, thereby creating the forward path, see Figure 1.

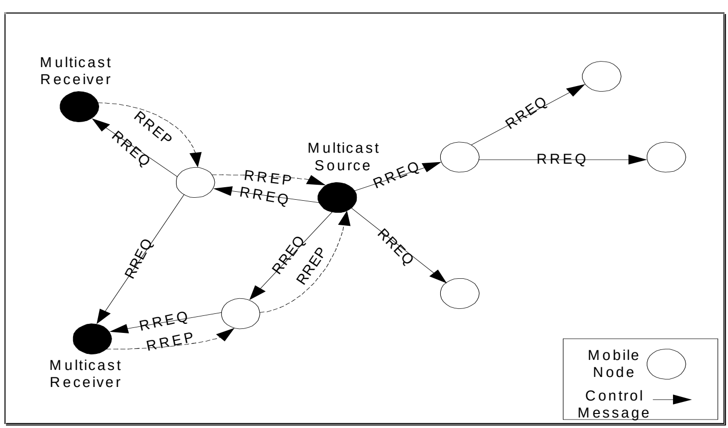

Figure 1: MAODV Path Discovery

When a source node broadcasts a RREQ for a multicast group, it often receives more than one reply. The source node keeps the received route with the greatest sequence number and shortest hop count to the nearest member of the multicast tree for a specified period of time, and disregards other routes. At the end of this period, it enables the selected next hop in its multicast route table, and unicasts an activation message (MACT) to this selected next hop. The next hop, on receiving this message, enables the entry for the source node in its multicast route table. If this node is a member of the multicast tree, it does not propagate the message any further. However, if this node is not a member of the multicast tree, it will have received one or more RREPs from its neighbours. It keeps the best next hop for its route to the multicast group, unicasts MACT to that next hop, and enables the corresponding entry in its multicast route table. This process continues until the node that originated the RREP (member of tree) is reached. The activation message ensures that the multicast tree does not have multiple paths to any tree node. Nodes only forward data packets along activated routes in their multicast route tables.

The first member of the multicast group becomes the leader for that group. The multicast group leader is responsible for maintaining the multicast group sequence number and broadcasting this number to the multicast group. This is done through a Group Hello message. The Group Hello contains extensions that indicate the multicast group IP address and sequence numbers (incremented every Group Hello) of all multicast groups for which the node is the group leader. Nodes use the Group Hello information to update their request table.

Since AODV keeps hard state in its routing table, the protocol has to actively track and react to changes in this tree. If a member terminates its membership with the group, the multicast tree requires pruning. Links in the tree are monitored to detect link breakages. When a link breakage is detected, the node that is further from the multicast group leader (downstream of the break) is responsible for repairing the broken link. If the tree cannot be reconnected, a new leader for the disconnected downstream node is chosen as follows. If the node that initiated the route rebuilding is a multicast group member, it becomes the new multicast group leader. On the other hand, if it was not a group member and has only one next hop for the tree, it prunes itself from the tree by sending its next hop a prune message. This continues until a group member is reached.

Once separate partitions reconnect, a node eventually receives a Group Hello for the multicast group that contains group leader information that differs from the information it already has. If this node is a member of the multicast group, and if it is a member of the partition whose group leader has the lower IP address, it can initiate reconnection of the multicast tree.

On-demand Multicast Routing Protocol

ODMRP (On-demand Multicast Routing Protocol) [6] is mesh based, and uses a forwarding group concept (only a subset of nodes forwards the multicast packets). A soft-state approach is taken in ODMRP to maintain multicast group members. No explicit control message is required to leave the group.

In ODMRP, group membership and multicast routes are established and updated by the source on demand. When a multicast source has packets to send, but no route to the multicast group, it broadcasts a Join-Query control packet to the entire network. This Join-Query packet is periodically broadcast to refresh the membership information and update routes, see Figure 2.

When an intermediate node receives the Join-Query packet, it stores the source ID and the sequence number in its message cache to detect any potential duplicates. The routing table is updated with the appropriate node ID (i.e. backward learning) from which the message was received for the reverse path back to the source node. If the message is not a duplicate and the Time-To-Live (TTL) is greater than zero, it is rebroadcast.

When the Join-Query packet reaches a multicast receiver, it creates and broadcasts a "Join Reply" to its neighbours. When a node receives a Join Reply, it checks if the next hop node ID of one of the entries matches its own ID. If it does, the node realizes that it is on the path to the source and thus is part of the forwarding group and sets the FG_FLAG (Forwarding Group Flag). It then broadcasts its own Join Table built upon matched entries. The next hop node ID field is filled by extracting information from its routing table. In this way, each forward group member propagates the Join Reply until it reaches the multicast source via the selected path (shortest). This whole process constructs (or updates) the routes from sources to receivers and builds a mesh of nodes, the forwarding group, see Figure 2.

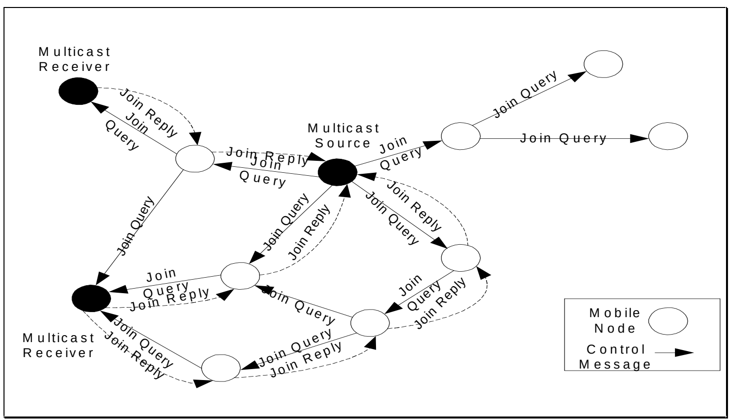

Figure 2 ODMRP Mesh Creation

After the forwarding group establishment and route construction process, sources can multicast packets to receivers via selected routes and forwarding groups. While it has data to send, the source periodically sends Join-Query packets to refresh the forwarding group and routes. When receiving the multicast data packet, a node forwards it only when it is not a duplicate and the setting of the FG_FLAG for the multicast group has not expired. This procedure minimizes the traffic overhead and prevents sending packets through stale routes.

In ODMRP, no explicit control packets need to be sent to join or leave the group. If a multicast source wants to leave the group, it simply stops sending Join-Query packets since it does not have any multicast data to send to the group. If a receiver no longer wants to receive from a particular multicast group, it does not send the Join Reply for that group.

Nodes in the forwarding group are demoted to non-forwarding nodes if not refreshed (no Join Tables received) before they timeout.

Qualitative Comparison of MAODV and ODMRP

The two on-demand protocols share certain salient characteristics. In particular, they both discover multicast routes only in the presence of data packets to be delivered to a multicast destination. Route discovery in either protocol is based on request and reply cycles where multicast route information is stored in all intermediate nodes on the multicast path. However, there are several important differences in the dynamics of the two protocols, which may give rise to significant performance differences.

First, MAODV uses a shared bi-directional multicast tree while ODMRP maintains a mesh topology rooted from each source. In MAODV, the tree is based on hard state and any link breakages force actions to repair the tree. A multicast group leader maintains up to date multicast tree information by sending periodic group hello messages. ODMRP provides alternative paths and a link failure need not trigger the recomputation of the mesh, broken links will time out (soft state). Routes from multicast source to receivers in ODMRP are periodically refreshed by the source. However, a bi-directional tree is more efficient and avoids sending duplicate packets to receivers. Also, depending on the refresh interval in ODMRP, the control overhead from sending route refreshes from every source could result in scalability issues

Second, ODMRP broadcasts the reply back to the source while MAODV unicasts the reply. By using broadcasts, ODMRP allows for multiple possible paths from the multicast source back to the receiver. Since MAODV unicasts the reply back to the source, if an intermediate node on the path moves away, the reply is lost, and the route is lost. However, a broadcasted reply requires intermediate nodes not interested in the multicast group to drop the control packets, resulting in extra processing overhead.

Third, MAODV does not activate a multicast route immediately while ODMRP does (unless mobility prediction is enabled). In MAODV, a potential multicast receiver must wait for a specified time allowing for multiple replies to be received before sending an activation message along the multicast route that it selects.

Simulation-based Comparison

The performance simulation environment used is based on *ns-2*, a network simulator that provides support for simulating multi-hop wireless networks complete with physical and IEEE 802.11 MAC layer models.

Experimental Setup and Performance Metrics

The simulated environment consists of 50 wireless mobile nodes roaming in a 1000 meters x 1000 meters flat space for 900 seconds of simulated time. The radio transmission range is 250 meters. A free space propagation channel is assumed. Group scenario files determine which nodes are receivers or sources and when they join or leave a group. A multicast member node joins the multicast group at the beginning of the simulation (first 30 seconds) and remains as a member throughout the whole simulation. Hence, the simulation experiments do not account for the overhead produced when a multicast member leaves a group. Multicast sources start and stop sending packets in the same fashion (four packets per second, each packet has a constant size of 512 bytes). Each data point represents an average of at least five runs with identical traffic models, but different randomly generated mobility scenarios. For fairness, identical mobility and traffic scenarios are used across the compared protocols. Only one multicast group was used for all the experiments.

Each mobile node moves randomly at a preset average speed according to a "random waypoint model". Here, each node starts its journey from a random location to a random destination with a randomly chosen speed (uniformly distributed between 0 – some maximum speed). Once the destination is reached, another random destination is targeted after a pause. By varying the pause time, the relative speeds of the mobiles are affected. In our experiments the pause time was always set to zero to create a harsher mobility environment. The maximum speeds used were chosen from between 1m/s to 20m/s.

The following metrics were used in comparing the protocol performance. The metrics were derived from ones suggested by the IETF MANET working group for routing/multicast protocol evaluation [3]:

- Packet Delivery Ratio: The ratio of the number of packets actually delivered to the destinations versus the number of data packets supposed to be received. This number presents the effectiveness of a protocol in delivering data to the intended receivers within the network.
- Number of data packets transmitted per data packet delivered: "Data packets transmitted" is the count of every individual transmission of data by each node over the entire network. This count includes transmissions of packets that are eventually dropped and retransmitted by intermediate nodes.
- Number of control packets transmitted per data packet delivered: This measure shows the efficiency overhead in control packets expended in delivering a data packet to an intended receiver.
- Number of control packets and data packets transmitted per data packet delivered: This measure tries to capture a protocol's channel access efficiency, as the cost of channel access is high in contention-based link layers.

To test the protocols, we performed a number of experiments to explore the performance of MAODV and ODMRP with respect to a number of parameters: number of senders, node mobility, and multicast group size. For more results please see [2].

Number of Senders

We varied the number of senders in the multicast group in order to evaluate the protocol scalability with respect to source nodes and the resulting effective traffic load. ODMRP is over 53% more effective than MAODV in data delivery ratio as the number of senders is increased from one to twenty. In terms of packet transmission ratio though, at twenty senders, MAODV sends 75% fewer packets for each data packet delivered than ODMRP. As well, MAODV sends 59% fewer control overhead packets than ODMRP for each data packet delivered as the number of senders reaches twenty. For both control and data transmissions, MAODV sends 90% less packets than ODMRP for every packet delivered as the number of senders reaches twenty.

We observed that ODMRP in particular does not scale well for packet delivery ratio as the number of senders increases along with the effective traffic load. In ODMRP, every source node will periodically send out route requests through the network. When the number of source nodes becomes larger, the effect of this causes congestion in the network and the data delivery ratio drops significantly. MAODV, on the other hand, maintains only one group leader for the multicast group that will send periodic Group Hellos through the network. In this manner, it is more scalable than ODMRP.

Node Mobility

We varied the mobility to evaluate the ability of the protocols to deal with route changes. ODMRP is over 104% more effective than AODV in data delivery ratio as the maximum node speed is increased from 1m/s to 20m/s. In terms of packet transmission ratio, ODMRP sends 40% less packets for each data packet delivered at high mobility (>15m/s). As well, for control overhead, ODMRP decreases by up to 74% less than MAODV for each data packet delivered as the mobility reaches 20m/s. For both control and data transmissions, ODMRP sends 48% less packets than MAODV for every packet delivered. We see that ODMRP is generally unaffected by increases in mobility, while MAODV is more sensitive to changes in mobility. The mesh topology of ODMRP allows for alternative paths thus making it more robust than MAODV. MAODV relies on a single path on its multicast tree, and must react to broken links, by initiating repairs.

Multicast Group Size

For the third set of simulations, we varied the number of members in the multicast group in order to evaluate the protocol scalability with respect to multicast group size. In Figure 3, ODMRP is 270% to 20% more effective than MAODV in data delivery ratio as the number of multicast group members is increased from ten to fifty. In terms of packet transmission ratio, in Figure 4, MAODV sends up to 48% less packets for each data packet delivered. As well, for control and data transmissions, from Figure 5, MAODV decreases by up to 46% less than ODMRP for each data packet delivered.

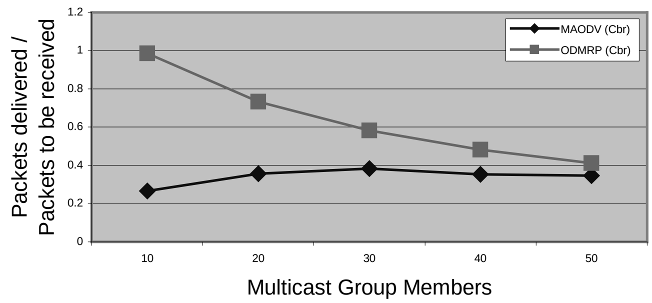

Figure 3: Data Delivery Ratio as a Function of Multicast Group Size

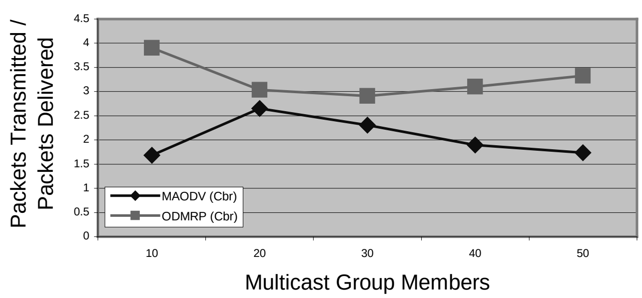

Figure 4: Packet Transmission Ratio as a Function of Multicast Group Size

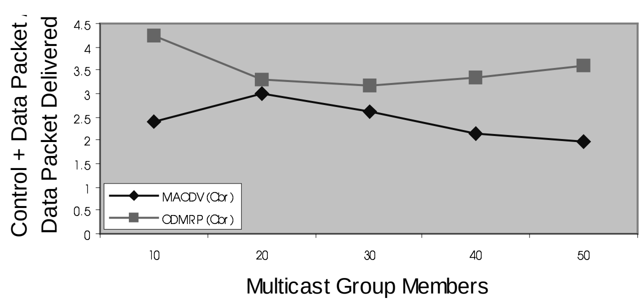

Figure 5: Control and Data Transmissions per Data Packet Delivered vs. Group Size

ODMRP does not scale well with multicast group size. There is a drastic decline in packet delivery ratio as the multicast group increases to fifty members. This can be attributed to collisions that occur from the frequent broadcasts through the network. Despite the poor data delivery ratio, we see that MAODV scales better in terms of overall control and data transmissions for every packet delivered.

Conclusions

Multicasting can efficiently support a wide variety of applications that are characterized by a close degree of collaboration, typical for many MANET applications currently envisioned. Within the wired network, well-established routing protocols exist to offer efficient multicasting service. As nodes become increasingly mobile, these protocols need to evolve to provide similarly efficient service in the new environment. Adopting wired multicast protocols to MANETs, which are completely lacking in infrastructure, appears less promising. These protocols, having been designed for fixed networks, may fail to keep up with node movements and frequent topology changes due to host mobility increase the protocol overheads substantially. Rather, new protocols that operate in an on-demand manner are being proposed and investigated. Existing studies and our results show that tree-based on-demand protocols are not necessarily the best choice. In a harsh environment, where the network topology changes very frequently, mesh-based protocols seem to outperform tree-based protocols, due to the availability of alternative paths, which allow multicast datagrams to be delivered to all or most multicast receivers even if links fail. Much room still exists to improve protocol performance (as measured by the packet delivery ratio) while reducing the associated overhead.

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