

On the Reliability and Additional Overhead of Reliable On-Demand Multicast Routing Protocol for Mobile Ad Hoc Networks

Kumaran Sambandan, Gergely V. Záruba, and David Levine
Department of Computer Science and Engineering, The University of Texas at Arlington
{kumaran, zaruba, levine}@cse.uta.edu

***Abstract** – Multicasting is the transmission of datagrams to a group of hosts identified by a single destination address, providing simple and efficient communication for group-oriented applications. Many applications currently envisioned for mobile ad hoc networks require multicasting. Several multicasting protocols have been proposed for mobile ad hoc networks, one of the most popular being the On Demand Multicast Routing Protocol. This paper provides a review of ad hoc multicast routing protocols, focusing on MAODV, ODMRP and a variation of ODMRP called reliable-ODMRP. NS-2 simulations are used to compare the reliability and overhead of MAODV, ODMRP, and R-ODMRP.*

1. Introduction

With the rapid development of wireless technologies in the past decade and due to the availability of inexpensive portable devices, wireless networks are expected to be in even greater widespread use in the future. Wireless networks can be classified into two types: i) infrastructure based wireless networks and ii) mobile ad hoc networks (MANET). Fixed infrastructure networks rely on fixed base stations (or access points) for communication (e.g., cellular networks). Ad hoc wireless networks are a collection of nodes, which form a network among themselves, each node functioning as a wireless router. Thus, they form self-organizing networks with dynamic topologies. Typical applications of ad hoc networks are spontaneous communication, emergency-response situations and on-the-fly conferencing. These applications require a close degree of co-operation between the nodes in the network.

Multicasting is the transmission of datagrams to a group of hosts identified by a single destination address. Multicasting can efficiently support the applications currently envisioned by group-oriented computing, utilizing the inherent broadcast nature of the wireless medium, minimizing bandwidth consumption, processing overhead and delay.

The most basic and simple technique to multicast group maintenance and creation is known as flooding. With flooding, every node that receives a packet in the network simply rebroadcasts it (except via the link in which the packet has arrived – if using unicasting). This causes all nodes in the network to eventually receive the packets. However this technique has several drawbacks as it induces network congestion and duplicate packets leading to a performance degradation of the network. This is highly undesirable in MANETs due to limited power and memory requirements.

Multicasting in ad hoc networks poses several challenges because of bandwidth-constrained links, high bit error rates, node mobility and hidden/exposed terminal effects. Multicast routing protocols should adapt to node mobility, and handle frequent changes in topology and variation in link quality gracefully. Routing protocols should be reliable, robust and scalable as the number of nodes in the multicast groups increases.

1.1. A Review of Ad Hoc Multicast Routing Protocols

Ad Hoc multicast routing protocols can be classified into two types: i) tree-based protocols; and ii) mesh based protocols. In tree-based protocols there is only one path between source and destinations (possibly, shortest paths) providing higher multicast efficiency. Some examples of tree based multicasting protocols are: Multicast Ad hoc On Demand Distance Vector (MAODV) routing protocol [1], Ad hoc Multicast Routing (AMRoute) protocol [5] and Multicast Core Extraction Distributed Ad hoc Routing (MCEADR) protocol [10].

In mesh based multicasting protocols there may be more than one path between source and destinations providing a more robust operation than the tree-based protocols. Some of the proposed mesh based routing protocols are On Demand Multicast Routing Protocol (ODMRP) [3], Forwarded Group Multicast Protocol (FGMP)[11] and Core Assisted Mesh Protocol (CAMP) [4].

Multicast Ad hoc On Demand Distance Vector Routing Protocol (MAODV)

Multicast Ad hoc On Demand Distance Vector (MAODV) routing is a tree-based protocol. It discovers routes by broadcast route discovery mechanism. Each node maintains three tables to maintain routing information: i) *route table*, ii) *multicast route table*, and iii) *request table*. Routes for multicasting are discovered in three phases: i) route request message generation, ii) reverse route establishment, and iii) route reply message generation. MAODV uses sequence numbers to eliminate stale routes. In the route request message generation phase a node that wishes to join a multicast group issues a *ROUTE-REQUEST (RREQ)* broadcast message. Any intermediate node with a valid route to the multicast group can respond. The nodes that receive *RREQ* update their routing tables, and set up pointers to establish the reverse routes. This may be used to relay the response back to the source. The join *RREQ* messages require some processing differences in intermediate nodes. A node receiving join *RREQ* updates its multicast route table in addition to the unicast route table.

If a node receives a join *RREQ* and it is a group member it responds to the *RREQ* by generating a Route Reply (*RREP*) message. It also updates its routing table and multicast route table and unicasts the *RREP* message towards the source. As the intermediate nodes receive *RREP* messages they also update their route tables and multicast route tables. The source issuing a *RREQ* may receive multiple *RREP* messages. It selects the best route by using the sequence numbers and hop counts. Once the route is selected the source will unicast the Multicast Activation (*MACT*) message to activate the entries in the multicast route table at intermediate nodes (until the destination is reached). The first multicast group member becomes the group leader responsible for maintaining group information and sending the group information to the members (e.g., broadcasting *Group Hello (GH)* messages periodically in the network).

1.2. On Demand Multicast Routing Protocol (ODMRP)

ODMRP is a mesh based protocol employing a forwarding group concept to transmit multicast packets to the destination. It is a reactive protocol as it uses on-demand procedures to dynamically build routes and maintain multicast group membership. By using a mesh topology, the drawbacks of tree protocols (e.g., intermittent connectivity, tree reconfigurations and shortest path computations) are avoided. ODMRP uses a soft-state approach to maintain multicast group members. There is no explicit control information needed to leave the group.

Figure 1 outlines the mesh creation process of ODMRP. Whenever a source has data to send, it floods the network with a *JOIN-DATA* message. When an intermediate node receives a (non-duplicate) *JOIN-DATA* packet, it updates its routing table storing the information about the upstream node. Intermediate nodes keep flooding the *JOIN-DATA* packet. When the *JOIN-DATA* packet reaches the receiver, it builds the *JOIN-TABLE* and sends the *JOIN-REPLY* to its neighbors.

The nodes that receive *JOIN-REPLY* packets check their own ID against the ID in the *JOIN-REPLY* packet. If they match, the node will set the *FG_FLAG* (Forward Group Flag) and becomes the forwarding member of the group. The *JOIN-REPLY* packet is propagated further to the network until it reaches the source. The senders periodically update the multicast group by broadcasting *JOIN-DATA* packets.

Each host running ODMRP needs to maintain the following data structures:

- Routing table - A route table is created reactively and maintained in each node. A routing entry is inserted or updated when a non-duplicate *JOIN-QUERY* is received. The node stores the destination and the next hop to the destination. The route table provides the next hop information when transmitting *JOIN-REPLIES*.
- Forwarding group table - When a node is a forwarding group node of a multicast group it stores the multicast group information in the forwarding group table. The multicast group ID and the time stamp are recorded.

- Message Cache - The message cache is maintained by nodes to detect duplicates. In AG the message cache will have recent history of the messages received. This will enable the protocol to recover the last messages in the gossip phase. The messages need not be maintained permanently in the message cache. FIFO or LRU algorithms can be used to remove the entries in the message cache.

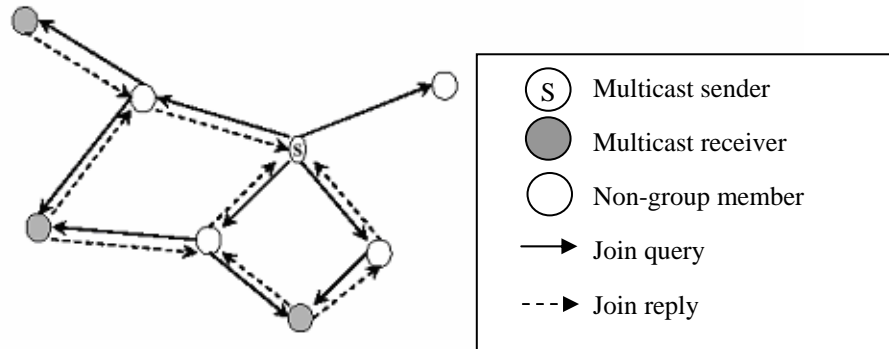


Figure 1. ODMRP membership setup and maintenance.

Ad hoc Multicast Routing (AMRoute)

AMRoute is a tree-based protocol. It creates a bi-directional shared multicast tree using unicast tunnels to provide connections between multicast group members. A node wanting to form a multicast group will create one with a core of size one. The core will then broadcast *JOIN-REQ* messages in the network. When a member node receives the *JOIN-REQ* it responds with *JOIN-ACK*, storing the information about the source of *JOIN-REQ*. This process creates a path from receiver to the source. After the mesh creation each source transmits *TREE-CREATE* messages. A node receiving a *TREE-CREATE* message will mark the path the message came from as a tree link. If a duplicate *TREE-CREATE* packet is received, a *TREE-CREATE-NAK* is sent back to the source. (This path is marked as mesh link by the node.) The processing overhead and route maintenance in AMRoute will only take place in nodes that are part of the multicast tree. The advantage of this protocol is its simplicity and ease of implementation.

Core-Assisted Mesh Protocol (CAMP)

CAMP generalizes the notion of core-based trees introduced for Internet multicasting into ad hoc multicast meshes that have much richer connectivity than trees [4]. CAMP can have multiple cores, which may or may not be part of the multicast group. The idea of having multiple cores is to limit the amount of control information exchanged in the network

CAMP classifies the nodes in the network into three classes: i) *simplex members*, ii) *full duplex members*, and iii) *non-members*. Simplex members have a one-way connection to the mesh. Simplex connections may exist between sender-only nodes and the multicasts mesh. Full duplex members have bi-directional connection to the mesh. CAMP consists of a mesh creation and maintenance procedure. The mesh creation consists of a request and a reply phase. A node wanting to join a multicast group will check its routing table to find the group address. If group address exists, it requests for membership using IGMP.

1.3. Comparison of multicasting protocols

MAODV uses bi-directional multicast tree and the tree is based on hard state. The routing information maintained consistently with network changes. MAODV uses hard state to maintain consistency in the routing information. The routes are established on demand with a small delay. It provides good routing efficiency and loop free operation. ODMRP provides high packet delivery ratio compared to MAODV [3]. The key feature of ODMRP is its mesh based structure and soft state maintenance of routing information. MAODV exploits the broadcast nature of wireless medium to construct the multicast mesh. The redundancy allows more robust operation even under high mobility. The overhead in ODMRP is less in high mobility because no control information has to be exchanged immediately in the network. AMRoute

is a simple but promising (due to its scalability) protocol [5]. It uses unidirectional links for data delivery, which is not reliable in high mobility. Another problem with AMRoute is that it is not loop-free and the possible formation of non-optimal trees.

CAMP provides good scalability because the sources and receivers need not flood control information. CAMP guarantees that there is a sub optimal path exists between the source and the destination. The disadvantage of CAMP is that it depends on correct operation of underlying protocol. CALM is a protocol proposed to improve reliability in multicast transmissions. It adopts an effective congestion control mechanism to improve reliability compared to scalable reliable multicast. Comparative studies of the multicast protocols [3,5] show that mesh protocols outperform tree based protocols. They provide more robust operation due to alternate paths. AMRoute performs well under light load and no mobility. MAODV suffers from excessive control overhead due to the broadcast of *RREQ* messages. CAMP uses cores to transmit control information, which limits the amount of control information need to be exchanged. MAODV could perform better if the concept of cores was used in route discovery process.

ODMRP performs well in most of the situations. It can co-exist with any underlying unicast protocol and it can also provide unicast capabilities. In application areas of ad hoc networks it is clear that the nature of underlying network is hidden from the applications, thus ODMRP is a good choice for IP level routing. ODMRP does not depend on underlying protocol for its correct operation. ODMRP possesses high packet delivery ratio compared to other protocols. These factors make ODMRP a favorite among ad hoc multicast routing protocols.

2. Reliable-ODMRP (RODMRP)

In [12] an extension has been suggested to improve the reliability of ODMRP, named RODMRP. The basic concept of RODMRP is to achieve the reliability through delivering data reliably to downstream forwarding group members and multicast receivers with a help of round robin window. The following sub sections outline the operation of RODMRP.

In RODMRP, when a node has a packet to send it initiates the join-query phase similar to basic ODMRP. During the join-reply phase the intermediate nodes create/update the neighbor lists by examining the incoming JOIN-REPLY packet. After updating the neighbor list, nodes randomly pick a destination in the list and the data will be forwarded with RODMRP header attached. RODMRP achieves reliability also through the reliable unicast mechanism of 802.11 MAC protocol.

RODMRP header contains the current sequence number of the data packet being sent and the lowest sequence numbers that has been sent so far. The lowest sequence number can be obtained from the `send_buffer`. These two sequence numbers provide the round-robin window that provides the range of messages that has been sent. The neighbor will receive the data packet and examine it's receive buffer to determine what sequence number is needed along with an acknowledgment. The acknowledgment will reflect the status of the received messages by the replying (receiver) node. After receiving the acknowledgment the sender will re-fetch the packet from the sent buffer. This process continues until all the messages are received by the destination.

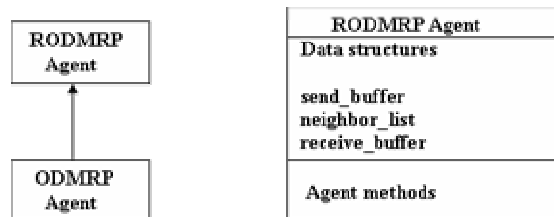


Figure 2. ROMDRP Agent.

3. Simulation Studies

To obtain performance results on R-ODMRP, we have conducted discrete event simulations using NS-2. In NS-2. Mobile nodes can be configured to use MAODV or ODMRP as a routing agent. The

employed network stack has a Link Layer (LL), an ARP module, an Interface Queue (IFq), a MAC layer and a Network Interface (NetIf). These network components are connected through OTcl. The routing agent receives both control packets and data packets. The link layer simulates the data link protocols. It also sets the MAC destination address in the MAC header of the packet. This function is implemented for two different issues: finding the next-hop-node's IP address and converting IP address into correct MAC address. The LL has an ARP module attached to it. The routing agent provides the outgoing packets to the LL which in turn hands them off to the node *entry_point*.

The LL sends the queries to ARP. If the ARP has the destination address, it writes the destination address to the packet. If not, an ARP query is broadcasted and the packet is cached temporarily. Once the hardware address is known, packets are fetched to the interface queue. The class *PriQueue* is implemented as a priority queue, which will insert routing packets at the head of the queue. It supports a running filter which scans over all packets in the queue and removes those with a specified destination address.

For the MAC layer, IEEE 802.11 Distributed Coordination Function (DCF) has been selected. It handles all the MAC layer functionality such as fragmentation, collision avoidance and acknowledgements. (It uses a four way handshaking mechanism for unicasting).

The Network Interface layer serves as the hardware interface that is used by the mobile nodes to access the channel. The radio propagation model receives the packets transmitted by other nodes' interfaces to the channel and applies a transfer function to them based on the propagation model selected.

3.1. Simulation Environment

Our simulations were set up in a 1000m x 1000m flat space for 900 seconds of simulation time. The radio transmission range was chosen to be 250 meters. A free space propagation channel model has been selected. A set of group scenario files were created to control the addition and removal of a source node to/from a group. We do not consider the overhead involved in removing members from groups. A multicast source transmits packets with a given rate. For the sake of simplicity one multicast group is used for all experiments. Each mobile node's mobility is assumed to follow "random way point model". Nodes start their motion from an I.I.D. uniform random location to an I.I.D. uniform random destination with an I.I.D. uniform random speed. When a node reaches its destination another destination is drawn randomly. The following metrics are used in analyzing the various protocols' performance:

- Packet delivery ratio: The ratio of number of packets actually delivered to the receivers versus the number of packets the receivers should have received. This metric represents the reliability of the protocol to deliver data to the intended recipients.
- Control overhead: Number of control packets transmitted per data packet delivered, i.e., shows the amount of overhead involved in delivering a data packet to the destination.

Table 1 provides the simulation parameters used to obtain our results.

Table 1. Simulation parameters.

Parameter	Value
Join-Query refresh interval	3 Sec
Forwarding group time out	9 Sec
Time-To-Live	20 Sec
Join-Reply ack time out	25 ms
Maximum JOIN REPLY retransmission	3 Sec

3.2. Simulation Results

Figure 3 depicts how the reliability of the investigated protocols change when the population of the multicast group is changed. The figure shows that R-ODMRP consistently outperforms ODMRP (and MAODV).

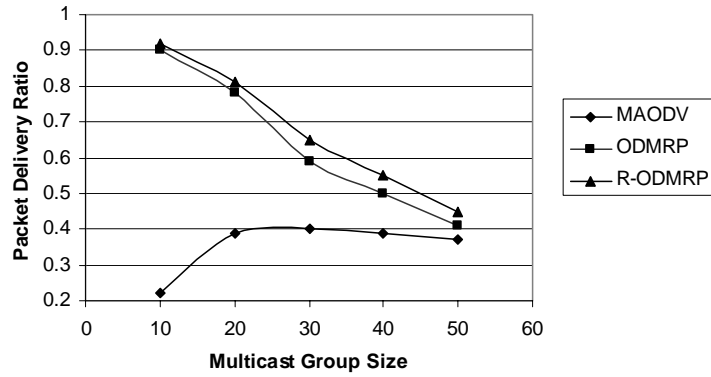


Figure 3. Packet delivery ratio versus multicast group size.

Figure 4 shows the control overhead as measured as a function of the multicast group population. As it can be observed R-ODMRP's additional overhead is comparable proportional to its additional reliability.

Figure 5 depicts the reliability measure of the three protocols versus the quantity of node mobility. Similar to Figure 3, R-ODMRP shows a consistent superiority. Figure 6 depicts the reliability of the protocols versus the offered load to the multicast group. R-ODMRP is observed to have the highest reliability significantly outperforming ODMRP at higher loads.

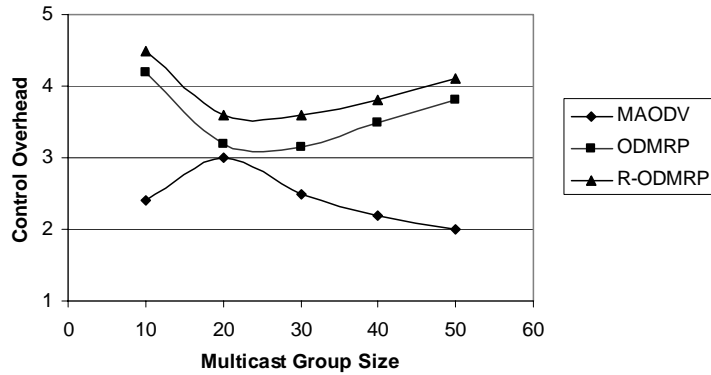


Figure 4. Control overhead versus multicast group size.

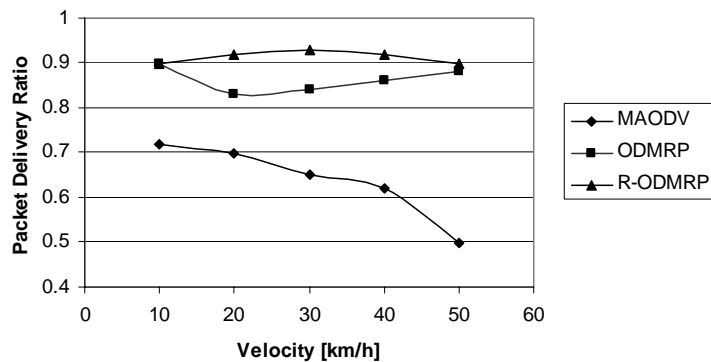


Figure 5. Packet delivery ratio versus node velocity.

4. Conclusions

Multicasting is the transmission of datagrams to a group of hosts identified by a single destination address. It provides the simple and efficient communication mechanism for group-oriented applications.

Various multicasting protocols have been proposed for mobile ad hoc networks. The most popular protocol among them is On Demand Multicast Routing Protocol (ODMRP). ODMRP provides better performance than MAODV (tree based protocols). But it suffers from scalability, excessive overhead, and reliability problems. This paper has also focused on an ODMRP spin-off protocol that increases ODMRP's reliability through reliable unicast messages (R-ODMRP). We have compared the performance of ODMRP, MAODV, and R-ODMRP and found that R-ODMRP improves reliability to the same extent as it increases overhead. We believe that incorporating local recovery schema in R-ODMRP may reduce this control overhead.

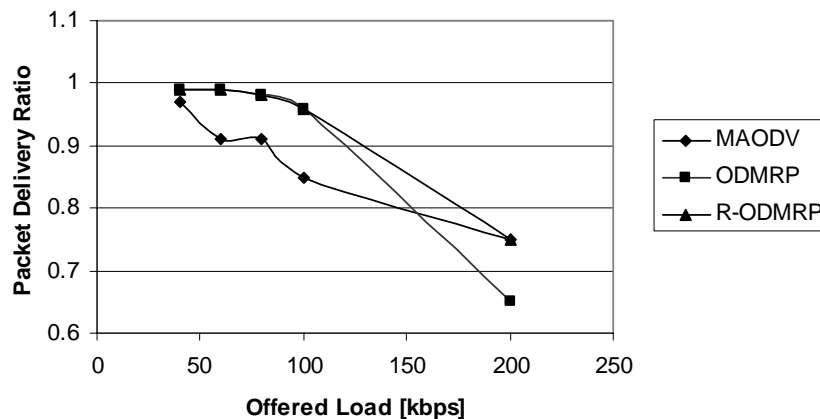


Figure 6. Packet delivery ratio versus offered load.

References

- [1] E. Royer, and C. E. Perkins "Multicast operation of the ad-hoc on-demand distance vector routing protocol", Proceedings of the 5th ACM/IEEE Annual Conference on Mobile Computing and Networking, pp. 207-218, August 1999.
- [2] S. Corson, and J. Macker "Mobile ad hoc networking (MANET): Routing protocol performance issues and evaluation considerations," RFC 2501, January 1999, <http://www.ietf.org/rfc/rfc2501.txt>.
- [3] T. Kunz, and E. Cheng, "Multicasting in ad-hoc networks: Comparing MAODV and ODMRP," Proceedings of the Workshop on Ad hoc Communications, Bonn, Germany, September 2001.
- [4] J.J. Garcia-Luna-Aceves, and E.L. Madruga, "A Multicast Routing Protocol for Ad-Hoc Networks," Proceedings of the IEEE INFOCOM '99, New York, March 21--25, 1999.
- [5] S-J. Lee, W. Su, J. Hsu, M. Gerla, and R. Bagrodia, "A Performance Comparison Study of Ad Hoc Wireless Multicast Protocols," Proceedings of the IEEE INFOCOM 2000, pp. 565-574, Tel Aviv, Israel, March 2000.
- [6] S.K. Das, B. S. Manoj, and C. Siva Ram Murthy, "Dynamic Core Based Multicast Routing Protocol for Ad hoc Wireless Networks," Proceedings of MobiHoc 2002, Lausanne, Switzerland June 2002.
- [7] E.M. Royer and C.K. Toh, "A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks," IEEE Personal Communications Magazine, April 1999, pp. 46-55.
- [8] K. Tang, K. Obraczka, S-J. Lee, and M. Gerla "Congestion Controlled Adaptive Lightweight Multicast in Wireless Mobile Ad Hoc Networks," Proceedings of IEEE ISCC 2002, Taormina, Italy, July 2002."
- [9] J. Luo, P. Th.Euster, J-P. Hubaux, "Technical Report No.IC/2002/50", July 10, 2002.
- [10] P. Sinha, R. Sivakumar, and V. Bharghavan, "CEDAR: Core extraction distributed ad hoc routing," Proceedings of IEEE INFOCOMM '99, 1999.
- [11] C.C. Chiang, M. Gerla, and L. Zhang, "Forwarding Group Multicasting Protocol for Multihop Mobile Wireless Networks," ACM-Kluwer Journal of Cluster Computing: Special Issue on Mobile Computing, vol. 1, no. 2, pp. 187-196, 1998.
- [12] K. Tang, and M. Gerla, "Reliable Multicast of the On-Demand Multicast Routing Protocol," Proceedings of SCI 2001, Orlando, Florida, July 2001.