On-Demand Multicast Routing Protocol

Sung-Ju Lee, Mario Gerla, and Ching-Chuan Chiang

Wireless Adaptive Mobility Laboratory
Computer Science Department
University of California
Los Angeles, CA 90095-1596
`http://www.cs.ucla.edu/NRL/wireless`

Abstract – This paper presents a novel multicast routing protocol for mobile ad hoc wireless networks. The protocol, termed ODMRP (On-Demand Multicast Routing Protocol), is a mesh-based, rather than a conventional tree-based, multicast scheme and uses a forwarding group concept (only a subset of nodes forwards the multicast packets via scoped flooding). It applies on-demand procedures to dynamically build routes and maintain multicast group membership. ODMRP is well suited for ad hoc wireless networks with mobile hosts where bandwidth is limited, topology changes frequently, and power is constrained. We evaluate ODMRP's scalability and performance via simulation.

I. INTRODUCTION

Multicasting has emerged as one of the most focused areas in the field of networking. As the technology and popularity of the Internet have grown, applications that require multicasting (e.g., video conferencing) are becoming more widespread. Another interesting recent development has been the emergence of dynamically reconfigurable wireless ad hoc networks to interconnect mobile users for applications ranging from disaster recovery to distributed collaborative computing. Multicast plays a key role in ad hoc networks because of the notion of teams and the need to show data/images to hold conferences among them. Protocols used in static networks (e.g., DVMRP [7], MOSPF [14], CBT [2], and PIM [8]), however, do not perform well in a dynamically changing ad hoc network environment. Multicast tree structures are fragile and must be readjusted continuously as connectivity changes. Furthermore, typical multicast trees usually require a global routing substructure such as link state or distance vector. The frequent exchange of routing vectors or link state tables, triggered by continuous topology changes, yields excessive channel and processing overhead. Limited bandwidth, constrained power, and mobility of network hosts make the multicast protocol design particularly challenging.

To overcome these limitations, we have developed the On-Demand Multicast Routing Protocol (ODMRP). ODMRP applies *on-demand* routing techniques to avoid channel overhead and improve scalability. It uses the concept of *forwarding group* [5], a set of nodes responsible for forwarding multicast data on shortest paths between any member pairs, to build a forwarding *mesh* for each multicast group. By maintaining

and using a mesh instead of a tree, the drawbacks of multicast trees in mobile wireless networks (e.g., intermittent connectivity, traffic concentration, frequent tree reconfiguration, non-shortest path in a shared tree, etc.) are avoided. A *soft-state* approach is taken in ODMRP to maintain multicast group members. No explicit control message is required to leave the group. We believe the reduction of channel/storage overhead and the relaxed connectivity make ODMRP more scalable for large networks and more stable for mobile wireless networks.

The rest of the paper is organized as follows. Section 2 describes the operation of ODMRP. Simulation results of ODMRP are reported in Section 3, and other ad hoc multicast protocols are overviewed in Section 4. Section 5 follows with a concluding remark.

II. ON-DEMAND MULTICAST ROUTING PROTOCOL OVERVIEW

A. Multicast Route and Membership Maintenance

In ODMRP, group membership and multicast routes are established and updated by the source *on demand*. Similar to on-demand unicast routing protocols, a request phase and a reply phase comprise the protocol (see Fig. 1). While a multicast source has packets to send, it periodically broadcasts to the entire network a member advertising packet, called a JOIN REQUEST. This periodic transmission refreshes the membership information and updates the route as follows. When a node receives a non-duplicate JOIN REQUEST, it stores the upstream node ID (i.e., backward learning) and rebroadcasts the packet. When the JOIN REQUEST packet reaches a multicast receiver, the receiver creates or updates the source entry in its *Member Table*. While valid entries exist in the *Member Table*, JOIN TABLES are broadcasted periodically to the neighbors. When a node receives a JOIN TABLE, it checks if the next 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. It then sets the FG_Flag and broadcasts its own JOIN TABLE built upon matched entries. The JOIN TABLE is thus propagated by each forwarding group member until it reaches the multicast source via the shortest path. This process constructs (or updates) the routes from sources to receivers and builds a mesh of nodes, the *forwarding group*.
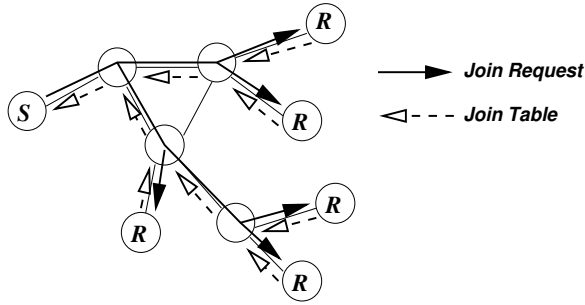
Fig. 1. On-Demand Procedure for Membership Setup and Maintenance.

Fig. 3. Why a Mesh?

We have visualized the forwarding group concept in Fig. 2. The forwarding group is a set of nodes in charge of forwarding multicast packets. It supports shortest paths between any member pairs. All nodes inside the "bubble" (multicast members and forwarding group nodes) forward multicast data packets. Note that a multicast receiver can also be a forwarding group node if it is on the path between a multicast source and another receiver. The mesh provides richer connectivity among multicast members compared to trees. Flooding redundancy among forwarding group helps overcome node displacements and channel fading. Hence, unlike trees, frequent reconfigurations are not required.

Fig. 3 is an example to show the robustness of a mesh configuration. Three sources (S_1, S_2, and S_3) send multicast data packets to three receivers (R_1, R_2, and R_3) via three forwarding group nodes (A, B, and C). Suppose the route from S_1 to R_2 is S_1-A-B-R_2. In a tree configuration, if the link between nodes A and B breaks or fails, R_2 cannot receive any packets from S_1 until the tree is reconfigured. ODMRP, on the other hand, already has a redundant route (e.g., S_1-A-C-B-R_2) to deliver packets without going through the broken link between nodes A and B.
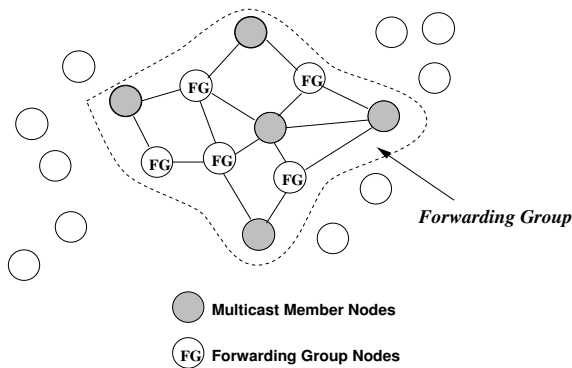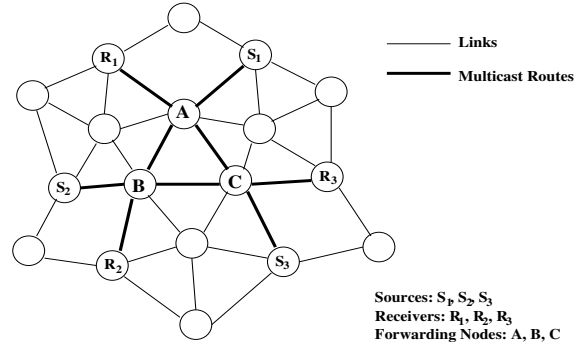
B. Example

Fig. 4 is shown as an example of a JOIN TABLE forwarding process. Nodes S_1 and S_2 are multicast sources, and nodes R_1, R_2, and R_3 are multicast receivers. Nodes R_2 and R_3 send their JOIN TABLES to both S_1 and S_2 via I_2, and R_1 sends its packet to S_1 via I_1 and to S_2 via I_2. When receivers send their JOIN TABLES to next hop nodes, an intermediate node I_1 sets the FG_Flag and builds its own JOIN TABLE since there is a next node ID entry in the JOIN TABLE received from R_1 that matches its ID. Note that the JOIN TABLE built by I_1 has an entry for sender S_1 but not for S_2 because the next node ID for S_2 in the received JOIN TABLE is not I_1. In the meantime, node I_2 sets the FG_Flag, constructs its own JOIN TABLE and sends it to its neighbors. Note that even though I_2 receives three JOIN TABLES from the receivers, it broadcasts the JOIN TABLE only once because the second and third table arrivals carry no new source information. Channel overhead is thus reduced dramatically in cases where numerous multicast receivers share the same links to the source.

C. Data Forwarding

After the group establishment and route construction process, a multicast source can transmit packets to receivers via selected routes and forwarding groups. Periodic control packets are sent only when outgoing data packets are still present.

Fig. 2. The Forwarding Group Concept.

Join Table of Node R_1

Sender	Next Node
S_1	I_1
S_2	I_2

Join Table of Node I_1

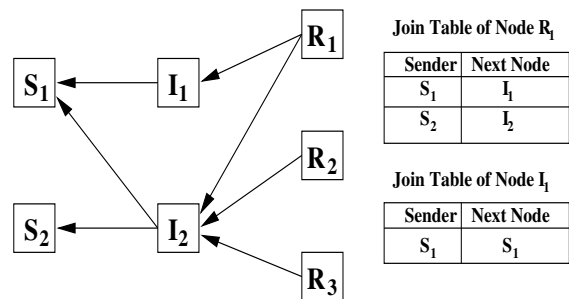| Sender	Next Node
S_1	S_1

Fig. 4. An Example of a Join Table Forwarding.

When receiving a multicast data packet, a node forwards it only if it is not a duplicate and the setting of the `FG_Flag` for the multicast group has not expired. This procedure minimizes traffic overhead and prevents sending packets through stale routes.

D. Soft State

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 REQUEST 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 removes the corresponding entries from its *Member Table* and does not transmit the JOIN TABLE for that group. Nodes in the forwarding group are demoted to non-forwarding nodes if not refreshed (no JOIN TABLES received) before they timeout.

E. Data Structures

Network hosts running ODMRP are required to maintain the following data structures.

- *Member Table*: Each multicast receiver stores the source information in the *Member Table*. For each multicast group the node is participating in, the source ID and the time when the last JOIN REQUEST is received from the source is recorded. If no JOIN REQUEST is received from a source within the refresh period, that entry is removed from the *Member Table*.
- *Routing Table*: A *Routing Table* is created on demand and is maintained by each node. An entry is inserted or updated when a non-duplicate JOIN REQUEST is received. The node stores the destination (i.e., the source of the JOIN REQUEST) and the next hop to the destination (i.e., the last node that propagated the JOIN REQUEST). The *Routing Table* provides the next hop information when transmitting *Join Tables*.
- *Forwarding Group Table*: When a node is a forwarding group node of the multicast group, it maintains the group information in the *Forwarding Group Table*. The multicast group ID and the time when the node was last refreshed is recorded.
- *Message Cache*: The *Message Cache* is maintained by each node to detect duplicates. When a node receives a new JOIN REQUEST or data, it stores the source ID and the sequence number of the packet. Note that entries in the *Message Cache* need not be maintained permanently. Schemes such as LRU (Least Recently Used) or FIFO (First In First Out) can be employed to expire and remove old entries and prevent the size of the *Message Cache* to be extensive.

F. Unicast Capability

One of the major strengths of ODMRP is its unicast routing capability. Not only ODMRP can work with any unicast routing protocol, it can function as both multicast and unicast. Thus, ODMRP can run without any underlying unicast protocol. Other ad hoc multicast routing protocols such as AM-Route [3], CAMP [9], RBM [6], and LAM [11] must be run on top of a unicast routing protocol. CAMP, RBM, and LAM in particular, only work on top of certain underlying unicast protocols.

III. PERFORMANCE EVALUATION

A. Simulation Environment

The simulator is implemented within the Global Mobile Simulation (GloMoSim) library [18]. The GloMoSim library is a scalable simulation environment for wireless network systems using the parallel discrete-event simulation capability provided by PARSEC [1]. Our simulation models a network of 50 mobile hosts placed randomly within a $1000m \times 1000m$ area. Radio propagation range for each node is 250 meters and channel capacity is 2 Mbits/sec. Each simulation executes for 300 seconds of simulation time. Multiple runs with different seed numbers are conducted for each scenario and collected data is averaged over those runs.

A free space propagation model [16] with a threshold cutoff is used in our experiments. In the free space model, the power of a signal attenuates as $1/d^2$ where d is the distance between radios. In the radio model, we assume the ability of a radio to lock on to a sufficiently strong signal in the presence of interfering signals, i.e., radio capture. If the capture ratio (the minimum ratio of an arriving packet's signal strength relative to those of other colliding packets) [16] is greater than the predefined threshold value, the arriving packet is received while other interfering packets are dropped. The IEEE 802.11 Distributed Coordination Function (DCF) [10] is used as the medium access control protocol. The scheme used is Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) with acknowledgments.

One multicast group with a single source is simulated. The source sends data at the rate of 20 packets/second. The size of data payload is 512 bytes. Multicast member nodes are randomly chosen with uniform probabilities. Members join the multicast group at the start of the simulation and remain as members throughout the simulation. Random waypoint [13] is used as the mobility model. A node randomly selects a destination and moves towards that destination at a predefined speed. Once the node arrives at the destination, it stays in its current position for a pause time between 0 and 10 seconds. After being stationary for the pause time, it selects another destination and repeats the same process. Mobility speed is varied from 0 km/hr to 72 km/hr.

The metrics used in ODMRP evaluation are:

- **Packet Delivery Ratio**: The number of data packet delivered to multicast receivers over the number of data packets supposed to be delivered to multicast receivers.
- **Number of Control Bytes Transmitted per Data Byte Delivered**: Instead of using a pure control overhead, we choose to use a ratio of control bytes transmitted to data byte delivered to investigate how efficiently control packets are utilized in delivering data. In addition to bytes of control packets (e.g., JOIN REQUESTS, JOIN TABLES), bytes of data packet headers are included in calculating control bytes transmitted. Accordingly, only bytes of the data payload contributes to the data bytes delivered.
- **Number of Data and Control Packets Transmitted per Data Packet Delivered**: This measure shows the efficiency in terms of channel access and is very important in ad hoc networks since link layer protocols are typically contention-based.

B. Simulation Results

Fig. 5 shows the packet delivery ratio of ODMRP as a function of mobility speed. The size of multicast group is varied to examine the scalability of the protocol. Having only two multicast members corresponds to a unicast situation. The result indicates that ODMRP delivers high portion of data packets in most of our scenarios. In highly mobile situations, the performance is the least effective in the two members case. When ODMRP functions as a unicast protocol, a mesh is not formed and there is no redundancy in packet forwarding. Since there are no multiple routes, the probability of packet drop increases with mobility speed. This performance degradation with speed increase also occurs in other unicast routing algorithms (see [4], [12]). As the number of members increases, the forwarding group mesh creates richer connectivity among members. The mesh makes the protocol scalable and robust to speed. In a tree configuration, a link break prevents packets from being delivered until the tree is reconfigured. But in the mesh, the data can still reach receivers via other redundant routes formed by the forwarding group nodes. We can see from the result that ODMRP delivers over 95% of multicast packets even in the face of high mobility.

The average number of control bytes transmitted per data byte delivered is shown in Fig. 6. We can see that ODMRP efficiently utilizes control packets in delivering data. JOIN REQUESTS are transmitted by the source only when it has data to send. JOIN TABLES are sent by receivers when valid sources exist in their *Member Table*. Thus, control packets are generated only if needed and all the control messages are utilized in establishing or refreshing routes and group membership. Furthermore, the transmission of control packets is periodic and the pure control overhead remains relatively constant regardless of mobility speed. As expected, the efficiency improves as the number of multicast members grows larger. Although more
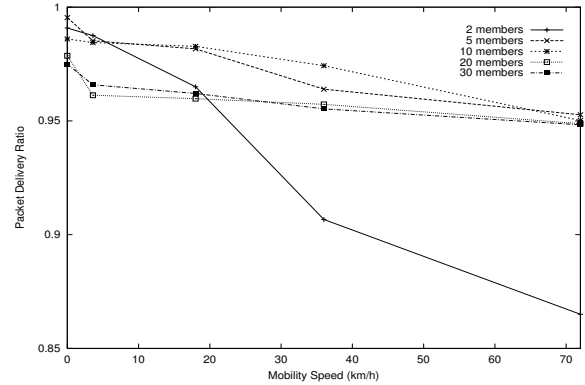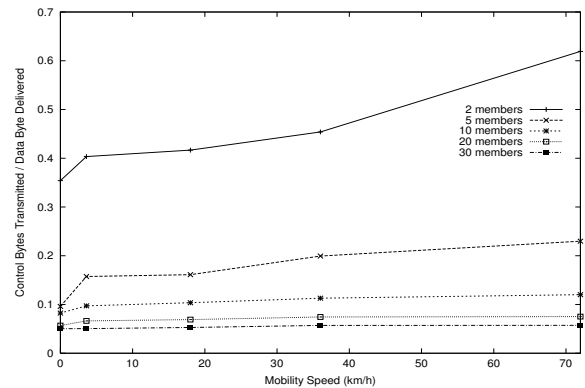

Fig. 5. Packet Delivery Ratio.

Fig. 6. Number of Control Bytes Transmitted per Data Byte Delivered.

JOIN TABLES are propagated when more nodes participate in a multicast group, the number of data delivered increases since more members receive the data.

Fig. 7 shows the average number of total packets transmitted per data packet delivered. Since most ad hoc network medium access control protocols are contention based, having less packets transmitted per data packet delivered is very important. When nodes contend less for the channel access, the probability of successfully delivering packets in a short time becomes higher. Similar to Fig. 6, the number remains relatively constant with varied speed and the protocol becomes more efficient when more multicast members exist. The result shows the channel access efficiency of ODMRP.

IV. RELATED WORKS

Other multicasting protocols have been proposed for ad hoc networks. The Reservation-Based Multicast (RBM) routing protocol [6] builds a core (or a Rendezvous Point) based tree for each multicast group. RBM is a combination of multicast, resource reservation, and admission control protocol where users specify requirements and constraints. The Lightweight Adaptive Multicast (LAM) algorithm [11] is a group shared
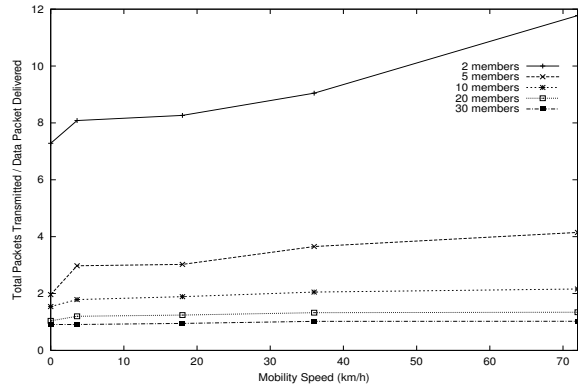
Fig. 7. Number of Total Packets Transmitted per Data Packet Delivered.

tree protocol that does not require timer-based messaging. Similar to other core-based protocols, it suffers from disadvantages of traffic concentration and vulnerability of the core. The Adhoc Multicast Routing Protocol (AMRoute) [3] is also a shared-tree protocol which allows dynamic core migration based on group membership and network configuration. The Ad hoc Multicast Routing protocol utilizing Increasing id-numberS (AMRIS) [19] builds a shared-tree to deliver multicast data. Each node in the multicast session is assigned an ID number and it adapts to connectivity changes by utilizing the ID numbers. A multicast extension of Ad Hoc On Demand Distance Vector (AODV) routing protocol has been newly proposed in [17]. Its uniqueness stems from the use of a destination sequence number for each multicast entry. The sequence number is generated by the multicast grouphead to prevent loops and to discard stale routes. Similar to ODMRP, the Core-Assisted Mesh Protocol (CAMP) uses a mesh. However, a conventional routing infrastructure based on enhanced distance vector algorithm (e.g., WRP [15]) is required for CAMP to operate. Core nodes are used to limit the traffic required when a node joins a multicast group.

V. CONCLUSIONS

We have proposed ODMRP (On-Demand Multicast Routing Protocol) for a mobile ad hoc wireless network. ODMRP is based on mesh (instead of tree) forwarding. It applies on-demand (as opposed to periodic) multicast route construction and membership maintenance. Simulation results show that ODMRP is effective and efficient in dynamic environments and scales well to a large number of multicast members. The advantages of ODMRP are:

- Low channel and storage overhead
- Usage of up-to-date and shortest routes
- Robustness to host mobility
- Maintenance and exploitation of multiple redundant paths
- Scalability to a large number of nodes

- Exploitation of the broadcast nature of wireless environments
- Unicast routing capability

Various improvements of the protocol are in progress and will be reported in an upcoming paper.

References

[1] R. Bagrodia, R. Meyer, M. Takai, Y. Chen, X. Zeng, J. Martin, and H.Y. Song, "PARSEC: A Parallel Simulation Environment for Complex Systems," *IEEE Computer*, vol. 31, no. 10, Oct. 1998, pp.77-85.

[2] T. Ballardie, P. Francis, and J. Crowcroft, "Core Based Trees (CBT) - An Architecture for Scalable Inter-Domain Multicast Routing," In *Proceedings of ACM SIGCOMM'93*, San Francisco, CA, Oct. 1993, pp. 85-95.

[3] E. Bommaiah, M. Liu, A. McAuley, and R. Talpade, "AM-Route: Adhoc Multicast Routing Protocol," *Internet-Draft*, draft-talpade-manet-amroute-00.txt, Aug. 1998, Work in progress.

[4] J. Broch, D.A. Maltz, D.B. Johnson, Y.-C. Hu, and J. Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," In *Proceedings of ACM/IEEE MOBICOM'98*, Dallas, TX, Oct. 1998, pp. 85-97.

[5] C.-C. Chiang, M. Gerla, and L. Zhang, "Forwarding Group Multicast Protocol (FGMP) for Multihop, Mobile Wireless Networks," *Baltzer Cluster Computing*, vol. 1, no. 2, 1998, pp. 187-196.

[6] M.S. Corson and S.G. Batsell, "A Reservation-Based Multicast (RBM) Routing Protocol for Mobile Networks: Initial Route Construction Phase," *ACM/Baltzer Wireless Networks*, vol. 1, no. 4, Dec. 1995, pp. 427-450.

[7] S.E. Deering and D.R. Cheriton, "Multicast Routing in Datagram Internetworks and Extended LANs," *ACM Transactions on Computer Systems*, vol. 8, no. 2, May 1990, pp. 85-110.

[8] S. Deering, D.L. Estrin, D. Farinacci, V. Jacobson, C.-G. Liu, and L. Wei, "The PIM Architecture for Wide-Area Multicast Routing," *IEEE/ACM Transactions on Networking*, vol. 4, no. 2, Apr. 1996, pp. 153-162.

[9] J.J. Garcia-Luna-Aceves and E.L. Madruga, "A Multicast Routing Protocol for Ad-Hoc Networks," In *Proceedings of IEEE INFOCOM'99*, New York, NY, Mar. 1999, pp. 784-792.

[10] IEEE Computer Society LAN MAN Standards Committee, *Wireless LAN Medium Access Protocol (MAC) and Physical Layer (PHY) Specification*, IEEE Std 802.11-1997. The Institute of Electrical and Electronics Engineers, New York, NY, 1997.

[11] L. Ji and M.S. Corson, "A Lightweight Adaptive Multicast Algorithm," In *Proceedings of IEEE GLOBECOM'98*, Sydney, Australia, Nov. 1998, pp. 1036-1042.

[12] P. Johansson, T. Larsson, N. Hedman, and B. Mielczarek, "Routing Protocols for Mobile Ad-hoc Networks - A Comparative Performance Analysis," To appear in *Proceedings of ACM/IEEE MOBICOM'99*, Seattle, WA, Aug. 1999.

[13] D.B. Johnson and D.A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," In *Mobile Computing*, edited by T. Imielinski and H. Korth, Chapter 5, Kluwer Publishing Company, 1996, pp. 153-181.

[14] J. Moy, "Multicast Routing Extensions for OSPF," *Communications of the ACM*, vol. 37, no. 8, Aug. 1994, pp. 61-66, 114.

[15] S. Murthy and J.J. Garcia-Luna-Aceves, "An Efficient Routing Protocol for Wireless Networks," *ACM/Baltzer Mobile Networks and Applications*, vol. 1, no. 2, Oct. 1996, pp. 183-197.

[16] T.S. Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall, Upper Saddle River, NJ, Oct. 1995.

[17] E.M. Royer and C.E. Perkins, "Multicast Operation of the Ad-hoc On-Demand Distance Vector Routing Protocol," To appear in *Proceedings of ACM/IEEE MOBICOM'99*, Seattle, WA, Aug. 1999.

[18] UCLA Parallel Computing Laboratory and Wireless Adaptive Mobility Laboratory, *GloMoSim: A Scalable Simulation Environment for Wireless and Wired Network Systems*.

[19] C.W. Wu, Y.C. Tay, and C.-K. Toh, "Ad hoc Multicast Routing protocol utilizing Increasing id-numberS (AMRIS) Functional Specification," *Internet-Draft*, draft-ietf-manet-amris-spec-00.txt, Nov. 1998, Work in progress.