Exploiting the Unicast Functionality of the On-Demand Multicast Routing Protocol

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Abstract – ***An ad hoc wireless network is composed of mobile hosts without any wired infrastructure support. In mobile ad hoc networks, unicast and multicast routing protocols are faced with the challenge of producing multihop routes because of limited radio propagation range. In addition, routing protocols must manage mobility and be bandwidth and power efficient. The On-Demand Multicast Routing Protocol (ODMRP) is a protocol designed for ad hoc networks with multicast purposes. Two unique features of ODMRP are its unicast capability and its utilization of a mobility prediction scheme to perform rerouting in anticipation of route disconnection. In this paper, we describe ODMRP unicast routing functionality and assess the mobility prediction effectiveness and effficiency. We evaluate the ODMRP performance via detailed simulation and compare it with other ad hoc routing schemes.***

I. INTRODUCTION

An ad hoc network [8], [10] is a dynamically reconfigurable wireless network with no fixed wired infrastructure. Each host is a router and moves in an arbitrary manner. Ad hoc networks are deployed in applications such as disaster recovery and distributed collaborative computing, where routes are mostly multihop and network hosts communicate via packet radios. In such a network, it is critical to route the packets to destinations without generating excessive control message overhead. Limited bandwidth, constrained power, and host mobility make the routing protocol design particularly challenging.

The On-Demand Multicast Routing Protocol (ODMRP) [11] is designed for ad hoc networks. Unicast routing capability is one of the major strengths of ODMRP. It can function as both multicast and unicast as well as coexist with any unicast routing protocol. Other ad hoc multicast protocols such as Adhoc Multicast Routing (AMRoute) [4], Reservation Based Multicast (RBM) [5], Core Assisted Mesh Protocol (CAMP) [6], and Lightweight Adaptive Multicast (LAM) [14] must run on top of a unicast routing protocol. CAMP, RBM, and LAM in particular, only work with certain underlying unicast protocols. ODMRP's another strength is its option to use mobility prediction in networks equipped with Global Positioning System (GPS) [15]. The primary goal of mobility prediction is to perform route reconstruction prior to topology changes. The use of mobility prediction helps minimize packet losses and efficiently utilize control packets.

ODMRP is known to perform best among ad hoc multicast protocols [13]. In this paper, we describe and evaluate the *unicast* routing ability of ODMRP and study the impact of using mobility prediction on ODMRP. The remainder of the paper is organized as follows. Section II overviews the ODMRP unicast mechanism. Section III follows with the simulation results and concluding remarks are made in Section IV.

II. UNICAST OPERATION OF ODMRP

In this section, we focus our attention and discussion on the unicast operation of ODMRP. Readers are referred to [12] for the multicast mechanism.

A. Basic Mechanism

ODMRP builds and maintains routes on demand by the source. A query phase and a reply phase comprise the protocol. When a source has to communicate with a node but no route information to that destination is known, it floods a control packet called JOIN QUERY with a piggybacked data payload. When a node receives a non-duplicate JOIN QUERY, it stores the last hop node information in its route table (i.e., backward learning) and rebroadcasts the packet. When the JOIN QUERY packet reaches the destination, the destination replies back to the source via the selected route with a JOIN REPLY packet.[1] Intermediate nodes of the route forward the JOIN REPLY to the next hop towards the source of the route. The next hop node information is obtained from the route table where the entry was recorded when JOIN QUERY was received. The JOIN REPLY packet is propagated until it reaches the source of the route. This process constructs the route from the source to the destination. Fig. 1 depicts the route $<S\text{-}i\text{-}j\text{-}k\text{-}D>$ establishment procedure.

One drawback of on-demand routing protocols is the route acquisition latency. Since routes are only built when needed, the source must wait until a route is established before transmitting data. To eliminate this delay, JOIN QUERY packets carry user data traffic in our protocol. Since the destination will receive the packet unless the network is partitioned, no

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[1] Packet types JOIN QUERY and JOIN REPLY have the term "Join" because ODMRP is originally a multicast protocol. These packets are exchanged to collect multicast group membership information as well as to build routes in multicast sessions, hence the term "Join." We keep the packet names the same in unicast mode even though group membership information is not obtained.

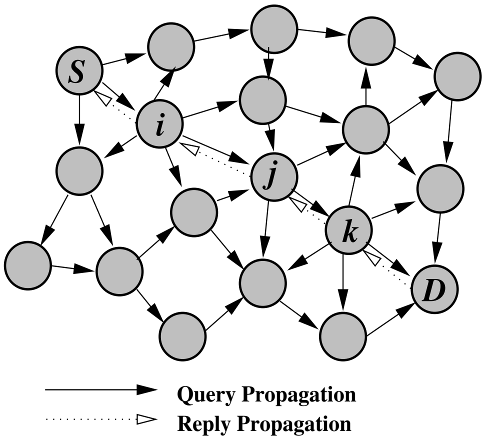

Fig. 1. On-Demand Procedure for Route Setup.

route acquisition delay is needed. The size of flooded packet however, becomes larger. There is a tradeoff between delay and efficiency. When data payload size is very large, we should avoid data piggybacking on JOIN QUERY.

To use the most recent route information, our protocol enforces two policies that are different from other well-known on-demand routing protocols such as Ad-hoc On-Demand Distance Vector (AODV) [20] and Dynamic Source Routing (DSR) [9]. First, intermediate nodes cannot send a JOIN REPLY in response to a JOIN QUERY even when they have route information to the destination node.[2] One reason is to deliver the JOIN QUERY data payload to the destination. If intermediate nodes send replies to the source and drop the JOIN QUERY packet, the destination cannot receive the data portion of the packet. The second reason is to utilize the most up-to-date topology information to build the shortest-distance route. Routes obtained from intermediate nodes yield longer hop distances since they do not account for node locations and network topology during and after node movements.

Second, as long as the source still need to communicate with the destination, JOIN QUERIES are periodically broadcasted to the entire network to refresh the route. Therefore, fresh routes are continuously built and utilized. We should adaptively select periodic route refresh interval based on network environment (for example, traffic type, traffic load, mobility pattern, mobility speed, channel capacity). When we use small route refresh intervals, we can frequently obtain fresh route information at the expense of producing more packets and causing network congestion. On the other hand, when we select large route refresh intervals, even though less control traffic will be generated, routes may not use fresh topology information. Thus in highly mobile networks, using large route refresh intervals will yield poor protocol performance.

Although the periodic route refresh reconstructs the routes, a node of the route sends a ROUTE ERROR message back to the source to invoke a fast route recovery process when it detects a route break during data propagation. Nodes detect a link disconnection either by MAC layer feedbacks using reliable MAC protocols such as IEEE 802.11 [7] and MACAW [3], or by passive acknowledgments [10]. The source, upon receiving the ROUTE ERROR packet, sends a JOIN QUERY for route recovery. In addition, it adjusts the next route refresh time to the current time plus the route refresh interval. Note that the ROUTE ERROR message does not exist in the ODMRP multicast operation since redundancy is created by multiple routes. In the unicast operation however, each <source, destination> pair maintains single path and no alternate route is available. Immediate route reconstruction is therefore necessary.

B. Adapting the Refresh Interval via Mobility Prediction

ODMRP requires periodic JOIN QUERY flooding to refresh routes. Excessive flooding, however, is not desirable in ad hoc networks because of bandwidth constraints. Furthermore, flooding often causes congestion, contention, and collisions. Finding the optimal refresh interval is critical in ODMRP performance. ODMRP utilizes a scheme that adapts the refresh interval to mobility pattern and speed. By using the location and mobility information provided by GPS, we predict the duration of time routes will remain valid.[3] Using this predicted route disconnection time allows the JOIN QUERY to be transmitted only shortly before the route becomes invalid. Therefore, the periodic JOIN QUERY flooding is no longer necessary.

In our prediction method, we assume a free space propagation model, [21], where the received signal strength solely depends on its distance to the transmitter. We also assume that all nodes in the network have their clock synchronized, for example, by using the NTP (Network Time Protocol) [17] or the GPS clock itself. If the motion parameters of two neighbors such as speed, direction, and radio propagation range are known, we can determine the duration of time these two nodes will remain connected. Assume two nodes i and j are within the transmission range r of each other. Let (x_i, y_i) be the coordinate of mobile host i and (x_j, y_j) be that of mobile host j. Also let v_i and v_j be the speeds, and θ_i and θ_j $(0 \leq \theta_i, \theta_j < 2\pi)$ be the moving directions of nodes i and j, respectively. Then, the amount of time two mobile hosts will stay connected, D_t, is predicted by:

$$D_t = \frac{-(ab+cd) + \sqrt{(a^2+c^2)r^2 - (ad-bc)^2}}{a^2+c^2}$$

where

$a = v_i \cos\theta_i - v_j \cos\theta_j$,
$b = x_i - x_j$,

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[2] Intermediate nodes can *relay* JOIN REPLIES from the destination to the source, of course.

[3] Mobility speed and direction information can be obtained from GPS or the node's own instruments and sensors (e.g., campus, odometer, speed sensors, etc.).

$c = v_i \sin\theta_i - v_j \sin\theta_j$, and
$d = y_i - y_j$.
Note that when $v_i = v_j$ and $\theta_i = \theta_j$, D_t is set to ∞ without applying the above equation.

To utilize the information obtained from the prediction, JOIN QUERY and JOIN REPLY packets must carry extra fields. When a source sends a JOIN QUERY, it appends its location, speed, and direction to the packet. It sets the MIN_LET (Minimum Link Expiration Time) field to the `MAX_LET_VALUE` since the source does not have any previous hop node. The next hop neighbor, upon receiving a JOIN QUERY, predicts the link expiration time between itself and the previous hop using the above equation. The minimum between this value and the MIN_LET indicated by the JOIN QUERY is included in the packet. The rationale is that when a single link on a path is disconnected, the entire path is invalidated. The node also overwrites the location and mobility information field written by the previous node with its own information. When the destination receives the JOIN QUERY, it predicts the LET of the last link of the path. The minimum between this value and the MIN_LET value specified in the JOIN QUERY is the Route Expiration Time (RET). This RET value is enclosed in the JOIN REPLY packet and sent back to the source along the route. When the source receives the JOIN REPLY, it updates the RET for the route. The source can then refresh the route by flooding a JOIN QUERY before the minimum RET approaches (i.e., route breaks).

In addition to the estimated RET value, we must consider other factors when selecting the route refresh interval.If the node mobility rate is high and the topology changes frequently, routes will expire quickly and often. The source may propagate JOIN QUERY excessively and this excessive flooding can cause collisions and congestion, and clogs the network with control packets. Thus, the `MIN_REFRESH_INTERVAL` should be enforced to avoid control message overflow. On the other hand, if nodes are stationary or move slowly and link connectivity remains unchanged for a long duration of time, routes will hardly expire and the source will rarely send JOIN QUERY. A problem arises in this situation. If a node in the route suddenly changes its movement direction or speed, the predicted RET value becomes obsolete and the route will not be reconstructed in time. Hence, the `MAX_REFRESH_INTERVAL` should be set. The selection of the `MIN_REFRESH_INTERVAL` and the `MAX_REFRESH_INTERVAL` values should be adaptive to network situations (e.g., traffic type, traffic load, mobility pattern, mobility speed, channel capacity, etc.). Route refresh interval hence should be carefully selected based on the estimated RET value and network condition.

C. Route Selection Strategy

Using the predicted route expiration time, a destination can select the route based on longevity. The idea is inspired by the Associativity-Based Routing (ABR) protocol [22] which chooses associatively stable routes. In our algorithm, a destination selects a route that is the most stable (the one with the largest RET). To select a route, a destination must wait for an appropriate amount of time after receiving the first JOIN QUERY so that all possible routes and their RETs will be known. The destination then chooses the most stable route and replies to the source with a JOIN REPLY. Route breaks will occur less often and the number of JOIN QUERY propagation will be reduced because stable routes are used.

D. Alternative Method of Prediction

Since GPS may not work properly in certain situations (for example, indoor environment, fading), we may not always be able to accurately predict the link expiration time for a particular link. There is an alternative method to predict the LET. This method is based on a more realistic propagation model and was proposed in [1] and [19]. Basically, transmission power samples are measured periodically from packets received from a mobile's neighbor. From this information it is possible to compute the change rate for a particular neighbor's transmission power level. Therefore, the time that the transmission power level drops below the acceptable value (hysteresis region) can be computed.

III. PERFORMANCE EVALUATION

A. Simulation Environment

We implemented the simulator in PARSEC [2] within the GloMoSim library [23]. The GloMoSim library is a scalable simulation environment for wireless network systems using the parallel discrete-event simulation capability provided by. Our simulation modeled a network of 50 mobile hosts placed randomly within a 1000 meters × 1000 meters area. Radio propagation range for each node was 250 meters and channel capacity was 2 Mb/s. Each simulation executed for 600 seconds of simulation time. Multiple runs with different seed numbers were conducted for each scenario and collected data were averaged over those runs.

Our experiments used a free space propagation model [21] with a threshold cutoff. 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 assumed 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) [21] was greater than the predefined threshold value, the arriving packet was received while other interfering packets were dropped.

The IEEE 802.11 Distributed Coordination Function (DCF) [7] was used as the medium access control protocol.

DCF is the mode which allows mobiles to share the wireless channel in an ad hoc configuration. The specific access scheme is Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) with acknowledgments. Optionally, the nodes can make use of Request To Send/Clear To Send (RTS/CTS) channel reservation control frames for unicast, virtual carrier sense, and fragmentation of packets larger than a given threshold. By setting timers based upon the reservations in RTS/CTS packets, the virtual carrier sense augments the physical carrier sense in determining when mobile nodes perceive that the medium is busy. Fragmentation is useful in the presence of high bit error and loss rates, as it reduces the size of the data units that need to be retransmitted. In our experiments, we employed RTS/CTS and virtual carrier sense. We chose this configuration to minimize the frequency and deleterious effects of collisions over the wireless medium. We did not employ fragmentation because our data packets were small enough that the additional overhead would reduce overall network throughput.

We developed a traffic generator to simulate constant bit rate sources. The sources and the destinations are randomly selected with uniform probabilities. Data payload size was 512 bytes.

Each node moved continuously with the predefined speed between zero and 72 km/hr. Nodes randomly selected the moving direction, and when they reached the simulation terrain boundary, they bounced back and continued to move.

B. Methodology

To evaluate the unicast performance of ODMRP, we simulated and compared the following schemes:

1. ODMRP (On-Demand Multicast Routing Protocol)
2. ODMRP-MP (On-Demand Multicast Routing Protocol with Mobility Prediction)
3. LAR (Location Aided Routing) [16] : an on demand routing protocol that uses GPS location information
4. WRP (Wireless Routing Protocol) [18] : a distance vector routing protocol for ad hoc networks

We evaluated all schemes as a function of speed.The number of data sessions was set to five and speed was varied from zero to 72 km/hr. In another set of experiments, to assess the impact of the mobility prediction, we directly compare the performance of ODMRP-MP with ODMRP by varying the route refresh interval of ODMRP. Periodic ODMRP route refresh interval was varied from 0.5 second to 4.0 seconds. Remember that ODMRP-MP adapts the refresh interval based on mobility prediction. Mobility speed was set to 36 km/hr and the number of data sessions was set to five. In the first set of experiments where ODMRP and ODMRP-MP performances were compared with LAR and WRP, the refresh interval of ODMRP was 1.5 seconds. In all the experiments, each source sends four data packets per second.

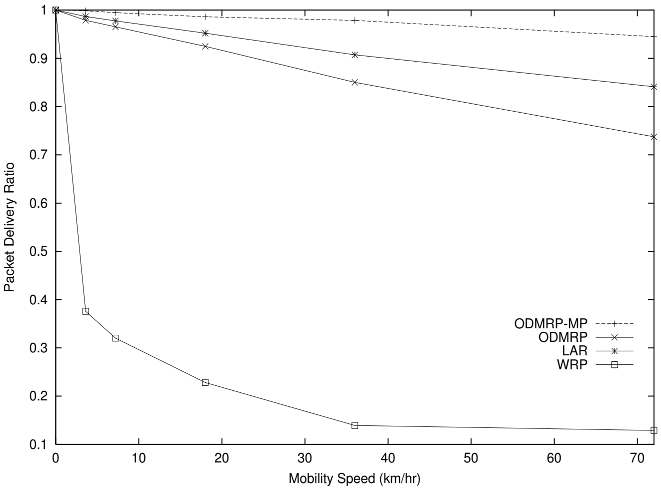

Fig. 2. Packet delivery ratio.

The metrics of interest are:

- **Packet delivery ratio**: The number of data received by destinations over the number of data sent by sources.
- **Number of control bytes transmitted per data byte delivered**: To investigate how efficiently control packets are utilized in delivering data, we use this metric instead of the pure control overhead. Only the data payload bytes contributes to the data bytes delivered. Accordingly, data packet header as well as control packets are included in the control byte overhead.
- **Number of total packets transmitted per data packet delivered**: The number of all packets (data and control packets) transmitted divided by the number of data packet delivered to destinations.

C. Simulation Results

C.1 Packet Delivery Ratio

The packet delivery ratio as a function of mobility speed is shown in Fig. 2.We can observe that as speed increases, the routing effectiveness of WRP degrades rapidly compared with other schemes. As nodes move faster, link connectivity changes more often and more update messages are triggered. For each triggered update, neighbor nodes are required to send back an acknowledgment. Moreover, temporary loops were being formed because the network view converged slowly, with many changes needing to be absorbed and propagated. Loops, triggered updates, and ACKs created an enormous amount of packets, contributing further to collisions, congestion, contention, and packet drops. ODMRP-MP is the least affected by the mobility speed. It is able to maintain delivery ratio

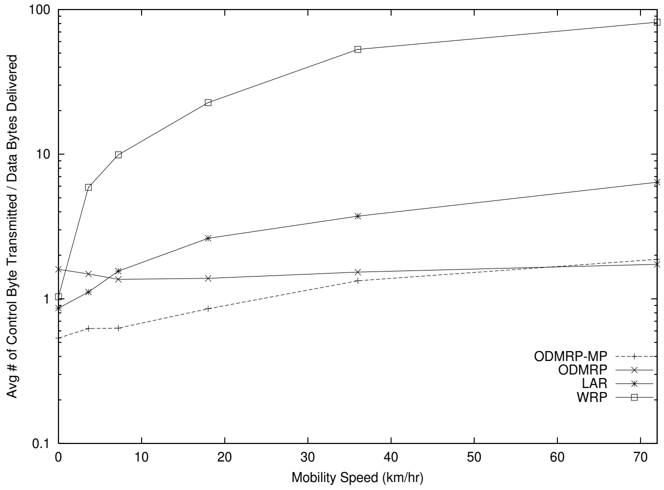

Fig. 3. The number of control bytes transmitted per data byte delivered.

above 0.9 for all mobility speeds in our experiments. Performing rerouting prior to route disconnection minimized packet losses.

C.2 Number of Control Bytes Transmitted per Data Byte Delivered

Fig. 3 shows the number of control bytes transmitted per data byte delivered as a function of mobility speed for each protocol. Remember that the control packet transmission in ODMRP is periodically triggered without adapting to mobility speed. The ratio for ODMRP hence does not increase as the mobility speed increases. On the other hand, the overhead of ODMRP-MP becomes larger as mobility speed increases. Since the scheme apples mobility prediction to adapt to mobility speed, more JOIN QUERY and JOIN REPLY packets are sent when mobility is high, thus resulting in more overhead. In WRP, route updates are produced more frequently in high mobility since there are more link changes. WRP has the highest ratio in mobile situations because of the small number of delivered data packets and the large number of triggered updates. LAR also shows more overhead as mobility speed increases because more route breaks occur and they invoke route recovery procedures.

C.3 Number of Total Packets Transmitted per Data Packet Delivered

The number of total packets (control packets and data packets) transmitted per data packet delivered is presented in Fig. 4. This measure shows the channel access efficiency and is very important in ad hoc networks since link layer protocols are typically contention-based. We can see that the numbers for ODMRP and ODMRP-MP remain relatively constant, with ODMRP-MP's ratio being lower than that of ODMRP. WRP has the highest ratio because of the same reasons described in Section III-C.2.

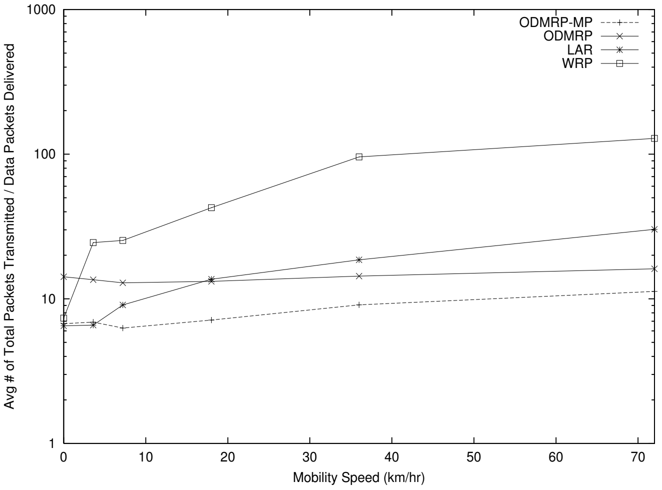

Fig. 4. The number of total packets transmitted per data packet delivered.

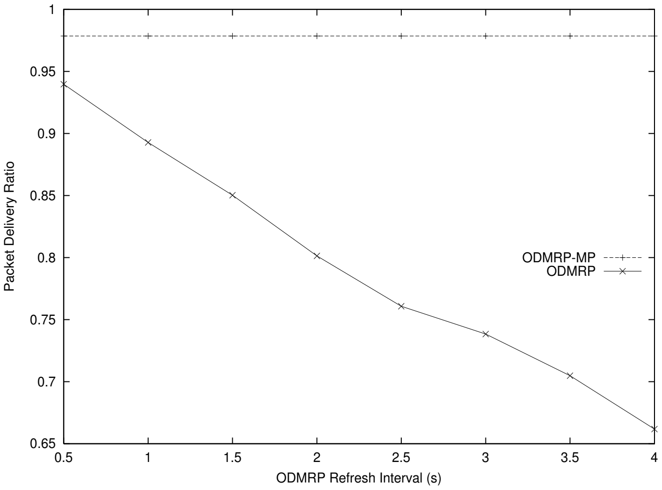

Fig. 5. ODMRP packet delivery ratio with and without mobility prediction.

C.4 Mobility Prediction Effectiveness

Since the basic ODMRP scheme rediscovers routes periodically, the performance of the protocol is highly dependent on the route refresh interval. When we shorten the refresh interval, packet delivery ratio may improve. Nevertheless, since JOIN QUERY is flooded more often, routing message overhead increases. With mobility prediction, JOIN QUERY is flooded only when necessary. High packet delivery ratios can be maintained without yielding a large amount of overhead. To assess the improvement of mobility prediction, we vary the route refresh interval of ODMRP and compare the performance with ODMRP-MP. Fig. 5 shows the packet delivery ratio as a function of route refresh interval. We can see that the ODMRP performance degrades rather rapidly when the refresh inter-

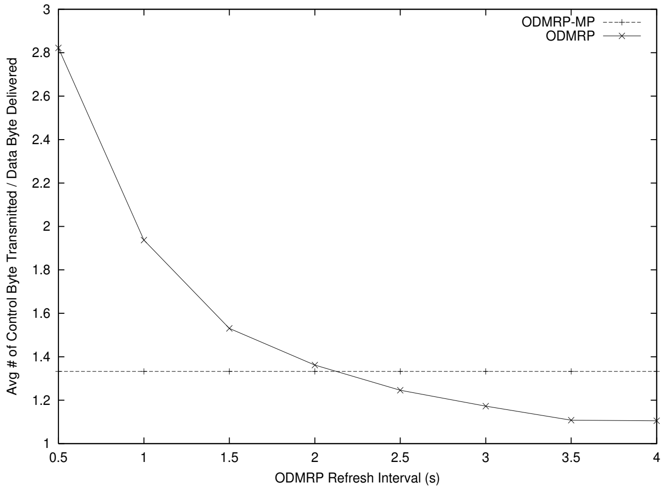

Fig. 6. The number of control bytes transmitted per data byte delivered with and without mobility prediction.

val is increased. As we increase the route refresh interval, the routes are not updated quickly and more packets are dropped. ODMRP-MP performs better than ODMRP regardless of the ODMRP route refresh interval. Fig. 6 shows the number of control bytes transmitted per data byte delivered. We can see that at small refresh intervals, the overhead of ODMRP is significantly greater than that of ODMRP-MP, but it decreases as the refresh interval is increased. In fact, ODMRP generates less overhead than ODMRP-MP when refresh interval is greater than 2.1 seconds. As seen in Fig. 5 however, packet delivery ratio of ODMRP drops as the interval is increased. We can analyze that the basic ODMRP does not efficiently utilize control packets when the route refresh interval is large.

IV. CONCLUSION

ODMRP is an ad hoc routing protocol that is capable of routing both unicast and multicast data. We described ODMRP unicast operation in detail and evaluated its performance by comparing it with other ad hoc unicast routing protocols. We also examined the impact of the mobility prediction on ODMRP performance to evaluate its effectiveness. Simulation results indicate that ODMRP is a competitive unicast protocol. The use of mobility prediction proved to be valuable and enhanced ODMRP performance. With mobility prediction, more data packets were delivered to destinations and the control packets were utilized more efficiently.

References

[1] P. Agrawal, D.K. Anvekar, and B. Narendran, "Optimal Prioritization of Handovers in Mobile Cellular Networks," *Proceedings of the* 5^{th} *Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communication (PIMRC)*, The Hague, Netherlands, September 1994, pp. 1393-1398.

[2] 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, October 1998, pp.77-85.

[3] V. Bharghavan, A. Demers, S. Shenker, and L. Zhang, "MACAW: A Media Access Protocol for Wireless LANs," *Proceedings of ACM SIGCOMM'94*, London, UK, September 1994, pp. 212-225.

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

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

[6] J.J. Garcia-Luna-Aceves and E.L. Madruga, "A Multicast Routing Protocol for Ad-Hoc Networks," *Proceedings of the IEEE Conference on Computer Communications (INFOCOM)*, New York, NY, March 1999, pp. 784-792.

[7] 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.

[8] Internet Engineering Task Force (IETF) Mobile Ad Hoc Networks (MANET) Working Group Charter, `http://www.ietf.org/html.charters/manet-charter.html`.

[9] D.B. Johnson and D.A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," In *Mobile Computing*, edited by Tomasz Imielinski and Hank Korth, Chapter 5, Kluwer Academic Publishers, 1996, pp. 153-181.

[10] J. Jubin and J.D. Tornow, "The DARPA Packet Radio Network Protocols," *Proceedings of the IEEE*, vol. 75, no. 1, January 1987, pp. 21-32.

[11] S.-J. Lee, M. Gerla, and C.-C. Chiang, "On-Demand Multicast Routing Protocol," *Proceedings of the IEEE Wirless Communications and Networking Conference (WCNC)*, New Orleans, LA, September 1999, pp. 1298-1302.

[12] S.-J. Lee, W. Su, and M. Gerla, "On-Demand Multicast Routing Protocol (ODMRP) for Ad Hoc Networks," *Internet-Draft*, draft-ietf-manet-odmrp-02.txt, January 2000, Work in progress.

[13] 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 Conference on Computer Communications (INFOCOM)*, Tel Aviv, Israel, March 2000, pp. 565-574.

[14] L. Ji and M.S. Corson, "A Lightweight Adaptive Multicast Algorithm," *Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM)*, Sydney, Australia, November 1998, pp. 1036-1042.

[15] E.D. Kaplan (Editor), *Understanding the GPS: Principles and Applications*, Artech House, Boston, MA, February 1996.

[16] Y.-B. Ko and N.H. Vaidya, "Location-Aided Routing (LAR) in Mobile Ad Hoc Networks," *Proceedings of the* 4^{th} *Annual ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM)*, Dallas, TX, October 1998, pp. 66-75.

[17] D.L. Mills, "Internet Time Synchronization: the Network Time Protocol," *IEEE Transactions on Communications*, vol. 39, no. 10, October 1991, pp. 1482-1493.

[18] S. Murthy and J.J. Garcia-Luna-Aceves, "An Efficient Routing Protocol for Wireless Networks," *ACM/Baltzer Journal of Mobile Networks and Applications (MONET)*, vol. 1, no. 2, October 1996, pp. 183-197.

[19] B. Narendran, P. Agrawal, and D.K. Anvekar, " Minimizing Cellular Handover Failures Without Channel Utilization Loss," *Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM)*, San Francisco, CA, December 1994, pp. 1679-1685.

[20] C.E. Perkins and E.M. Royer, "Ad-Hoc On Demand Distance Vector Routing," *Proceedings of the* 2^{nd} *IEEE Workshop on Mobile Computing Systems and Applications (WMCSA)*, New Orleans, LA, February 1999, pp. 90-100.

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

[22] C.-K. Toh, "Associativity-Based Routing for Ad-Hoc Mobile Networks," *Wireless Personal Communications Journal*, Kluwer Academic Publishers, vol. 4, no. 2, March 1997, pp. 103-139.

[23] UCLA Parallel Computing Laboratory and Wireless Adaptive Mobility Laboratory, *GloMoSim: A Scalable Simulation Environment for Wireless and Wired Network Systems*, `http://pcl.cs.ucla.edu/projects/domains/glomosim.html`.