MOBILITY PREDICTION IN WIRELESS NETWORKS

William Su
Sung-Ju Lee
Mario Gerla

Computer Science Department
University of California
Los Angeles, CA 90095-1596

***Abstract* – Wireless networks allow a more flexible communication model than traditional networks since the user is not limited to a fixed physical location. Unlike cellular wireless networks, ad hoc wireless networks do not have any fixed communication infrastructure. In ad hoc networks, routes are mostly multihop and network hosts communicate via packet radios. Each host moves in an arbitrary manner and thus routes are subject to frequent disconnections. In typical mobile networks, nodes exhibit some degree of regularity in the mobility pattern. By exploiting a mobile user's non-random traveling pattern, we can predict the future state of network topology and thus provide a transparent network access during the period of topology changes. In this paper we present various enhancements to unicast and multicast routing protocols using mobility prediction. The proposed scheme utilizes GPS location information. By simulation, we evaluate the effectiveness of mobility prediction.**

I. INTRODUCTION

Wireless networks allow a more flexible communication model than traditional wireline networks since the user is not limited to a fixed physical location. Unlike cellular wireless networks, mobile ad hoc networks [3] do not have any fixed wired communication infrastructure. 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. Each host moves in an arbitrary manner and routes are subject to frequent disconnections. Mobility presents a challenging issue for protocol design since the protocol must adapt to frequent changing network topologies in a way that is transparent to the end user.

In typical mobile networks, nodes exhibit some degree of regularity in mobility patterns. For example, a car traveling on a road is likely to follow the path of the road and a tank traveling across a battlefield is likely to maintain its heading and speed for some period of time. By exploiting a mobile user's non-random traveling pattern, we can predict the future state of the network topology and provide a transparent network access during the period of topology changes. Moreover, by using the predicted information, we can reduce the number of control packets needed to reconstruct routes and thus minimize overhead.

In this paper we present mobility prediction to enhance unicast and multicast routing protocols. The proposed scheme utilizes GPS location information [5]. In our protocol, GPS position information is piggybacked on data packets during a live connection and is used to estimate the expiration time of the link between two adjacent nodes. Based on this prediction, routes are reconfigured before they disconnect. Our goal is to provide a seamless connection service by reacting before the connection breaks.

The remainder of this paper is organized as follows. Section II presents the method used to predict the link expiration time (LET) and various ways to enhance unicast and multicast routing protocols by using mobility prediction. Section III describes the simulation environment used in our experiments. In Section IV, we evaluate the effectiveness of mobility prediction by simulation. In addition, we study the impact of inaccurate prediction on routing protocol performance. Concluding remarks are made in Section V.

II. MOBILITY PREDICTION

A. Basic Mechanism

In our approach, we assume a free space propagation model [10], 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) [8] or the GPS clock itself. Therefore, 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

$a = v_i \cos\theta_i - v_j \cos\theta_j$,
$b = x_i - x_j$,
$c = v_i \sin\theta_i - v_j \sin\theta_j$, and
$d = y_i - y_j$.

Note that when $v_i = v_j$ and $\theta_i = \theta_j$, D_t becomes ∞. The predicted value is the link expiration time (LET) between the two nodes.

B. Application of Mobility Prediction

In this section, we describe protocols that utilize the mobility prediction mechanism explained in Section II-A. Three protocols are introduced. The first two are unicast protocols with different routing philosophies (i.e., reactive and proactive), and the third is a multicast protocol.

B.1 Flow Oriented Routing Protocol

The Flow Oriented Routing Protocol (FORP) [12] is an on-demand routing scheme that uses mobility prediction. Only active routes are maintained and permanent route tables are not needed. When the source has a flow to send, it constructs a route to the destination on demand and injects the flow. The destination predicts the change in topology ahead of time and determines when the flow needs to be rerouted or "handoffed" based on the mobility information contained in data packets. We make the assumption that a given node is able to predict the link disconnection time of its one-hop neighbors. The basic concept is that if we can predict the LET along each hop on the route, we are able to predict the route expiration time (RET). RET is the minimum of the LETs along the route.

Figure 1 shows an example of flow setup process. In Figure 1(a), the source node A sends a FLOW-REQ message to destination node F. Nodes B, C, D, and E forward the FLOW-REQ message and append information of their node IDs and the LET of the link that the message was received from. Therefore, two FLOW-REQ messages arrive at node F. One contains a path $<A,B,C,E,F>$ with LETs = $<4,4,3,6>$, and the other contains a path $<A,B,D,E,F>$ with LETs = $<4,5,4,6>$. Since RET is the minimum of the set of LETs for the route, node F obtains the RET for both routes. Path $<A,B,D,E,F>$ is more stable since it has a larger RET value of four compared with three of path $<A,B,C,E,F>$, and is chosen as the route to set up the flow. As shown in Figure 1(b), node F then sends a FLOW-SETUP message and intermediate nodes set up the flow states.

B.2 Distance Vector with Mobility Prediction

Distance vector routing protocols maintain the most recent routing information by exchanging route tables with neighbor nodes. The performance of distance vector protocols is very sensitive to the periodic update interval. In high mobility conditions, routes need to be updated more often and the update interval must be shortened to handle mobility. Shorter update intervals however, increase routing overhead.

We propose Distance Vector with Mobility Prediction (DV-MP) [11]. The protocol uses the route expiration time as the metric in the route table. Triggered update transmissions are eliminated because routes are established based on stability. Hence, routing update interval is relaxed and frequent updates are not required. In addition, using stable routes minimizes the disruption caused by mobility since a different route with a greater expiration time is used prior to a given route gets disconnected.

To utilize the prediction information (LET and RET), mobility vector field must be appended to the route update packet. In addition, the RET metric is inserted into routing table entry. Each node periodically broadcasts a route table. A sequence number is issued when generating updates, and

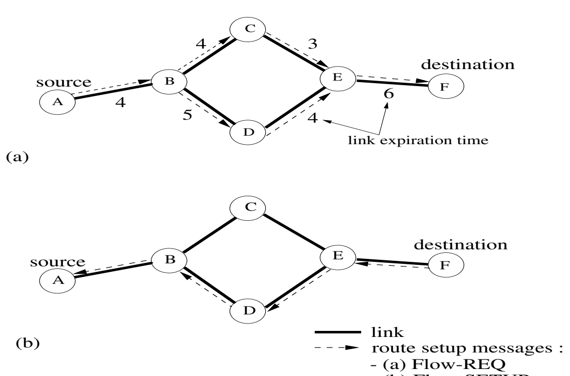

Fig. 1. The flow setup process.

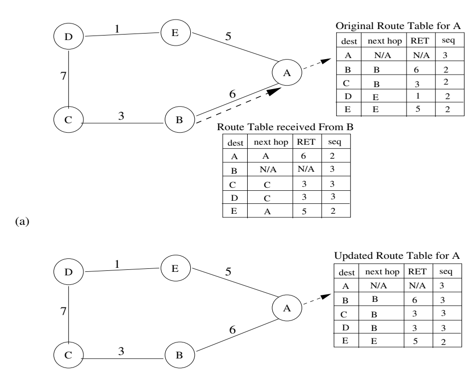

Fig. 2. A routing table update example.

it is incremented after each route table broadcast. The sequence number is associated with routing table entries for a particular origin of the route update. When node A receives a route table from its neighbor node B, the LET between nodes A and B is calculated based on the mobility vector contained in the received route table. Node A's route table is updated with the following rules:

- If an entry for destination D with a better RET is received and the received sequence number is greater than or equal to the old entry's sequence number, node A's entry for destination D is updated.
- If an entry for destination D with a higher sequence number is received, node A's entry for destination D is updated.

Figure 2 illustrates route table updating process. Values shown next to each link are LETs. In Figure 2(a), node A's next hop to node D is node E and the RET through node E is 1. After node A receives the route update packet from node B, it updates its next hop for destination D to node B as shown in Figure 2(b) since the route via node B has a higher RET value of three.

There is a tradeoff between route distance and route stability. A route that has the largest RET will remain connected the longest, but may not have the shortest hop and/or delay.

B.3 On-Demand Multicast Routing Protocol

The On-Demand Multicast Routing Protocol (ODMRP) [7] delivers data to multicast members using a mesh instead of a tree. The source establishes and updates group membership and multicast routes on demand. A query phase and a reply phase construct routes from sources to receivers and build a mesh of nodes, the "forwarding group."

Figure 3 visualizes the forwarding group concept. The forwarding group is a set of nodes which is in charge of delivering 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 also can 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 with trees. Flooding redundancy among forwarding group helps overcome node displacements and channel fading. Hence, unlike trees, frequent reconfigurations are not required.

ODMRP requires periodic flooding to build and 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 flooding interval is critical in ODMRP performance. By using mobility prediction, ODMRP can adapt the flooding interval to mobility patterns and speeds. With the predicted time of route disconnection, query packets are only flooded when route breaks of ongoing data sessions are imminent.

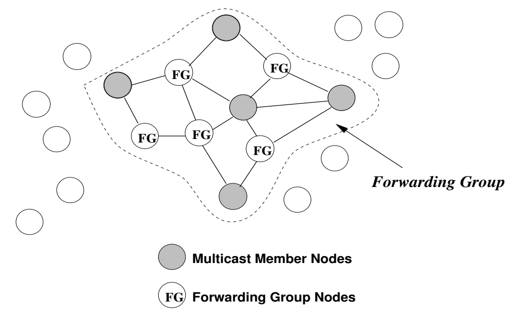

Fig. 3. The forwarding group concept.

C. Prediction Accuracy

So far we assumed nodes have simple mobility patterns (for example, no sudden change of direction and constant velocity). Under these conditions, we can accurately predict route disconnection times. This assumption however, cannot hold in some scenarios. A node accelerates, decelerates, and changes direction during movements. All these factors make mobility prediction inaccurate since such events are generally not predictable. In Section IV, we investigate the impact of prediction accuracy on routing performance.

III. SIMULATION ENVIRONMENT

We implemented the simulator within the Global Mobile Simulation (GloMoSim) library [13]. 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 modeled a network of 50 mobile hosts placed randomly within a 1000 meter × 1000 meter area. Each node has a radio propagation range of 250 meters and channel capacity was 2 Mb/s.

Our experiments used a free space propagation model with a threshold cutoff [10]. 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. The IEEE 802.11 Distributed Coordination Function (DCF) [2] was used as the medium access control protocol. We developed a traffic generator to simulate constant bit rate sources. The size of data payload was 512 bytes. Each node moved constantly with the predefined speed. Nodes randomly selected moving direction, and when they reached the simula-

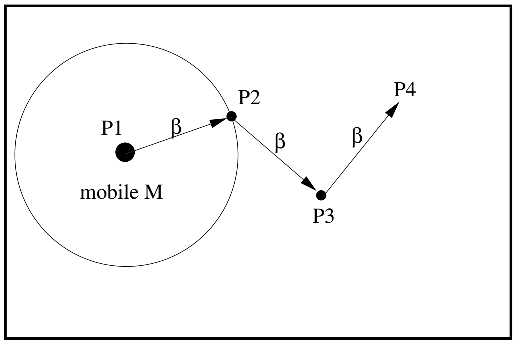

Fig. 4. The modified waypoint model.

tion terrain boundary, they bounced back and continued to move.

The following unicast protocols are evaluated: FORP (Flow Oriented Routing Protocol), DV-MP (Distance Vector protocol with Mobility Prediction), LAR (Location Aided Routing) [6], an on demand routing protocol that uses GPS, and WRP (Wireless Routing Protocol) [9], a distance vector routing protocol for ad hoc networks.

For multicast protocols, we measure the performance improvements made with mobility prediction by simulating ODMRP-MP (ODMRP with Mobility Prediction), and ODMRP (ODMRP *without* mobility prediction).

We also investigate the impact of prediction accuracy on protocol performance. We simulated DV-MP and DV (Distance Vector *without* mobility prediction). The conditions we varied in this scenario are the frequency of direction changes and the waypoint distance in the random waypoint mobility model [4]. In this experiment, we make modification to the waypoint model by limiting the waypoint distance (the distance between two successive random destinations) to β as shown in Figure 4. Therefore, when node M reaches a waypoint P_1, a new waypoint P_2 is selected with distance β. This process is repeated when P_2 is reached, and so on. Sine node M changes its direction each time a new waypoint is reached, decreasing the waypoint distance β will increase the randomness of mobility.

IV. PERFORMANCE EVALUATION

A. Unicast Protocols

Figure 5 shows the packet delivery ratio as a function of mobility speed. We can see 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. FORP and DV-MP are the schemes that are the least affected by mobility, maintaining delivery ratios above 0.9 for all mobility speeds. Using mobility prediction to perform rerouting prior to route disconnection and to send data over more stable routes minimized packet losses.

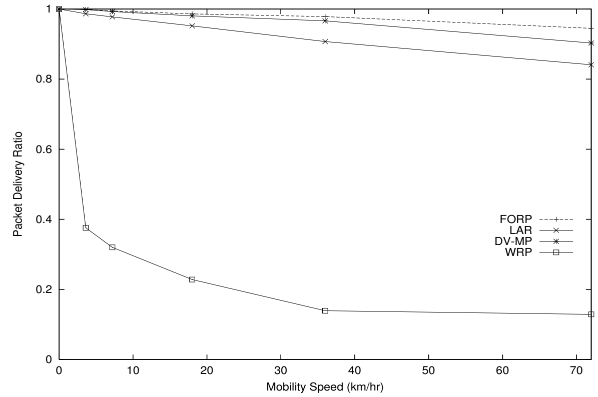

Fig. 5. Packet delivery ratio as a function of mobility speed.

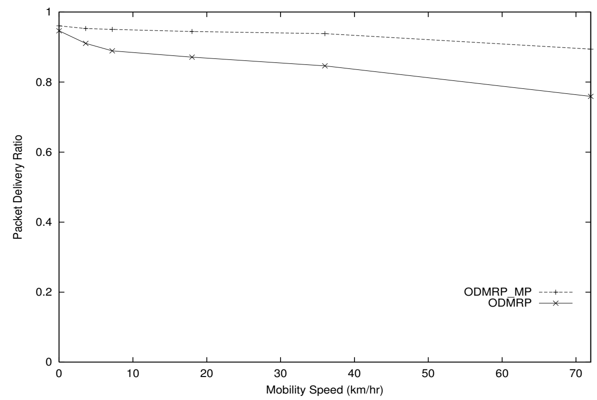

Fig. 6. Packet delivery ratio as a function of mobility speed.

B. Multicast Protocols

Figure 6 shows the packet delivery ratio as a function of mobility speed. As speed increases, the routing effectiveness of ODMRP degrades rapidly compared with ODMRP-MP. ODMRP-MP has a very high delivery ratio (over 90%) regardless of speed. As the routes are reconstructed in advance of topology changes, most data are delivered to multicast receivers without being dropped. In ODMRP, on the contrary, query and reply control messages are transmitted periodically without adapting to mobility speed and direction. At high speeds, routes that are taken at the query phase may already be broken when reply packets are propagated.

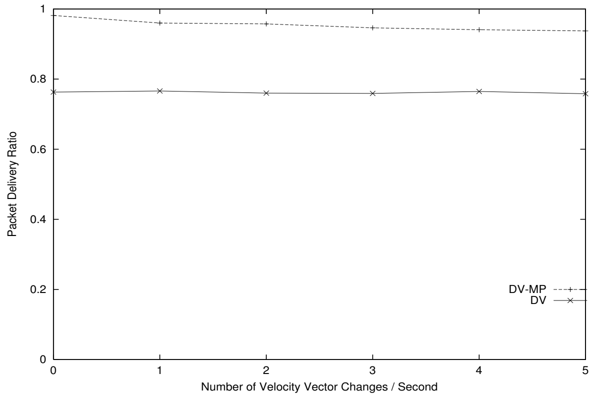

Fig. 7. Packet delivery ratio as a function of direction changing frequency.

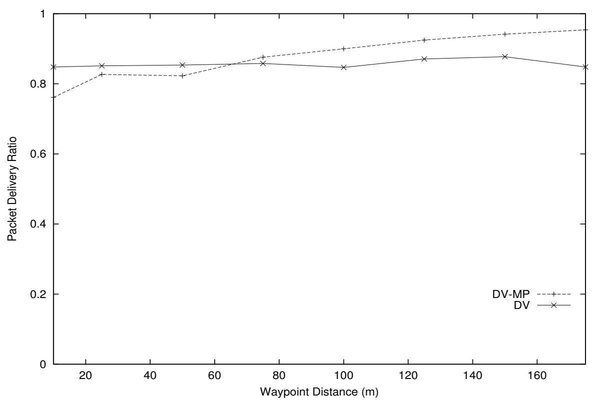

Fig. 8. Packet delivery ratio as a function of waypoint distance.

C. *Influence of Prediction Error*

C.1 Influence of Changing Direction on Performance

The result as a function of direction changing rate is shown in Figure 7. We can see that the packet delivery ratio for DV is not affected by the change rate and it maintains a steady ratio of above 0.76. The delivery ratio of DV-MP is as high as 0.98 when there is no moving direction changes and it drops to 0.95 when the change rate is increased to 5 per second. When direction changing frequency increases, prediction becomes less accurate and causes the delivery ratio to drop.

C.2 Influence of Waypoint Distance on Performance

Figure 8 shows the packet delivery ratio as a function of waypoint distance. DV's delivery ratio remains near 0.85 regardless of the waypoint distance. DV-MP is more sensitive to waypoint distance. As waypoint distance decreases, the chance of data packets being dropped increases because incorrect route tables are disseminated when nodes change their direction. The delivery ratio for DV-MP is significantly higher than DV when waypoint distance is farther than 70 meters. In real life scenarios (such as battlefield and search and rescue), nodes generally maintain trajectory for at least hundreds of meters. Therefore, we can expect the prediction method to be effective.

V. CONCLUSION

Effectively delivering data packets and minimizing connection disruption are crucial in ad hoc networks. In this paper we examined the use of mobility prediction to anticipate topology changes and perform rerouting prior to route breaks. We applied mobility prediction mechanism to some of the most popular representatives of the wireless ad hoc routing family, namely an on-demand unicast routing protocol, a distance vector routing protocol, and a multicast routing protocol. Routes that stay connected longest are chosen by utilizing the mobility prediction. Simulation results indicate that with mobility prediction enhancements, more data packets were delivered to destinations.

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