Mobility Prediction based Routing for Minimizing Control Overhead in Mobile Ad hoc Networks

R. Chellappa Doss, A. Jennings, N. Shenoy

Deakin Univeristy, Melbourne, Australia {rchell@deakin.edu.au}
RMIT University, Melbourne, Australia {ajennings@rmit.edu.au}
Rochester Institute of Technology, New York, U.S.A {ns@it.rit.edu}

***Abstract*—Routing in ad hoc networks faces significant challenges due to node mobility and dynamic network topology. In this work we propose the use of mobility prediction to reduce the search space required for route discovery. A method of mobility prediction making use of a sectorized cluster structure is described with the proposal of the Prediction based Location Aided routing (P-LAR) protocol. Simulation study and analytical results of the of P-LAR find it to offer considerable saving in the amount of routing traffic generated during the route discovery phase.**

Keywords—Ad hoc Networks, Routing, Control Overhead, Mobility Prediction.

I. INTRODUCTION

Ad hoc networks are self-organizing and self-configuring multi-hop networks where the network structure changes dynamically due to node mobility [1]. All nodes are capable of movement and can be connected dynamically in an arbitrary manner. Nodes of the network function as mobile routers that discover and maintain routes to other nodes in the network. Clustering in ad hoc networks enhances network manageability and energy economy. Since clusters are dynamic groupings mobile nodes frequently leave their current cluster of membership and join a neighbouring cluster. In this work we describe the enhanced sector-cluster concept that simplifies routing. We propose a prediction based on-demand routing protocol built on Location Aided Routing (LAR) [2], called Prediction based LAR (P-LAR). We employ a method of node mobility prediction to reduce the search space required for route discovery, which in turn reduces the route discovery overhead of the protocol. Mobility prediction can also assist in efficient route reconstruction procedures. Knowledge of discrete user movements enables new routes to be set up prior to expiry of current ones making possible seamless communication. P-LAR is found to significantly reduce management overhead in comparison to existing approaches. In Section II we describe related work with the proposed approach developed in Section III. In Section IV we present our simulation results and conclude in Section V.

II. RELATED WORK

Routing in ad hoc networks faces extreme challenges from node mobility/dynamics, potentially very large number of nodes and limited communication resources (e.g., bandwidth and energy)[3]. As ad hoc routing protocols need to adapt quickly to frequent and unpredictable topology changes conventional routing strategies are inefficient. Frequent update of routing tables is wasteful of the limited wireless bandwidth and hence a need to reduce routing traffic. While considerable research has been focussed to address the routing problem in ad hoc networks [4] not all algorithms take into account the physical location of a destination node. Location information can be used for directional routing not possible with basic flooding algorithms and results in reduction of routing overhead. Geographic Addressing and Routing (GeoCast) [5] forwards routing messages to all nodes in a specified geographic area rather than to node addresses. The Distance Routing Effect Algorithm for Mobility (DREAM) [6] is a proactive routing protocol using location information aimed at providing distributed, loop-free, multipath routing. Realizing the principles of distance effect and mobility rate it minimizes routing overhead. Greedy Perimeter Stateless Routing (GPSR) [7] uses neighbour location information in forwarding data packets. It requires only a small amount of per-node routing state, has a low routing message complexity, and works best for dense wireless networks. Location Trace Aided Routing (LOTAR) [8] is based on an on-demand scheme and utilizes location information to aid in routing. It is suited to support real time traffic, as it is able to keep low packet loss rates even in a high mobility environment. Location information is used to limit the search area, predict the route lifetime and handover a flow to a better route. Each node in the network maintains a Location Table (LT), Routing Table (RT) and a Checking Table (CT). The route discovery mechanism is similar to the one in LAR. However with the help of the LT the request area and the expected area can be more accurately defined.

Location Aided Routing (LAR) defines the Expected Zone and the Request Zone to aid in route discovery and limit the flooding area. The expected zone of a node D with respect to a node S is the region in which node S expects to find node D at a time t_1. The request zone is defined to limit the number of nodes forwarding the route request. The request zone must include the expected zone and both S and D nodes. If a path cannot be found within a predefined time period then the entire network space is included in the following route request. In LAR scheme 1, the request zone is defined as the smallest rectangle that contains the current location of the source and the expected zone of the destination such that the sides of the rectangle are parallel to the co-ordinate axes. In

LAR scheme 2, the request zone is not specified explicitly by the route request message. The source node S includes two pieces of information in its route request-the distance of S from the destination D ($DIST_S$), and the positional co-ordinates (X_d, Y_d) of node D. When a node I receives the route request it is able to calculate its distance from the destination and forwards the message only if its position is closer or not much farther from D than node S. The route message is forwarded by a node J only if it is closer to D than the forwarding node to J.

III. Prediction based location Aided Routing

In this work we introduce the Prediction based Location Aided Routing (P-LAR) for mobile ad hoc networks. P-LAR employs the sectorized ad hoc mobility prediction technique [9] with an enhanced sector-cluster concept to obtain a discrete approximation of the user location. This eliminates the need for continuous location updates. The sectorized ad hoc mobility prediction technique maintains a high level of prediction accuracy for all types of mobile users with minimal control overhead. Depending on the position of the user the search space is restricted to the current and predicted locations, thus reducing the route discovery overhead. This method of routing is best suited for cluster based ad hoc networks.

A. Motivation

The rationale for the proposed method is that maximum information of the location of the destination node can reduce the area of route request to a minimum.

Next generation ad hoc networks require routing strategies that are able to discover new paths with minimum route discovery overhead and maintain or reconstruct routes to destination nodes at almost real-time. While it may be impossible to maintain routes real-time, prior knowledge of user movements can ensure route reconstruction procedures to be completed prior to route failure or in 'pseudo real-time'. We aim to minimize the routing related traffic.

B. The Enhanced Sectorized Cluster Structure

The enhanced sector-cluster concept borrows foundational principles from the sectorized cluster structure [9]. The location of the user is defined relative to the cluster head. The cluster head has complete knowledge of each of its member nodes. The region of the cluster is divided into sectors as in Fig. 1. In addition to the C-type cluster-sectors C_1, C_2, C_3 and S-type cluster-sectors S_1, S_2, S_3 defined for cluster change prediction we also introduce boundary sectors in between adjacent sectors. Boundary sectors aid in prediction of sector changes within the cluster and is the region between adjacent clusters where the probability of sector change is high. The width of the boundary sector can be user dependant with highly mobile users having a wider boundary sector than less mobile users. We further define the optimal region (speckled-grey region in Fig.1) as the region of the cluster that includes n nodes but no more than (n+x) nodes in closest proximity to each other. The purpose of this region is to eliminate the involvement of far lying nodes in the first stages of route construction. The optimal region is expanded until a route is successfully constructed. There is also defined the Hi-CC region-which is the region where there is a high probability of cluster change. The Hi-CC region is the area of the cluster (dark outer circle) where the node is tracked for cluster change prediction purposes. By predicting cluster changes routes can be reconstructed prior to existing route failure. To predict the movement of a user in the Hi-CC region we make use of the cluster-sector numbering scheme as described in our previous work [9]. The numbering scheme forms a basis for prediction of the next cluster change. Prediction is cluster-sector-wise and not physical location-wise as the need is only to predict the next connection point of the mobile user.

C. The P-LAR Route Discovery Mechanism

Maximum information about the movement of the user restricts the size of the request area to a minimum. We make use of the expected zone & request zone concepts of Location Aided Routing with our definition of these zones based on the sectorized cluster structure. The Expected Zone is defined as the current cluster-sector of the user and the next predicted cluster-sector if applicable. The Request Zone includes the sector(s) of the expected zone to ensure that a path is constructed even if the user has changed its position of network connection. The request zone determines which of the nodes in the network forward the route request thus reducing the number of route request messages generated.

1) Intra-Cluster Route Discovery:

As the source and destination nodes are located within the same cluster the request zone can be restricted to the cluster-sectors within their cluster of membership depending on whether or not the destination is a candidate for cluster change. If the user is a candidate for cluster change, the predicted cluster sector is included in the request zone. If the destination node is located in one of the boundary sectors and is a candidate for sector change then both adjacent cluster-sectors are included in the request zone. The request zone is determined as in Fig. 2. In order to construct a route from S to D we include the sectors of residence of S and D and the optimal region denoted by r (i) of the cluster as the initial route request area. If a route request reply is not received within a certain time period then we increase the optimal region of the cluster indicated by r (j) to include more number of nodes. The optimal region is increased until a route request reply message is received. It is only in sectors of S (sector 2) and D (sector 5) that routes are forwarded outside the optimal region circle. All nodes within and without the optimal circle employ the distance rule in that a node forwards a route request only if it is closer in distance to the destination node than the forwarding node to it (non forwarding nodes u & m). As the destination D is mobile it is possible that it might have moved since the route request was generated. If the node was in a boundary sector then the route request area includes both current and predicted sectors. We include both sectors to accommodate possibly oscillating destinations. If the destination node is out of the boundary sector prior to route discovery procedures being completed, the route request area is reduced to include only the new cluster-sector of residence.

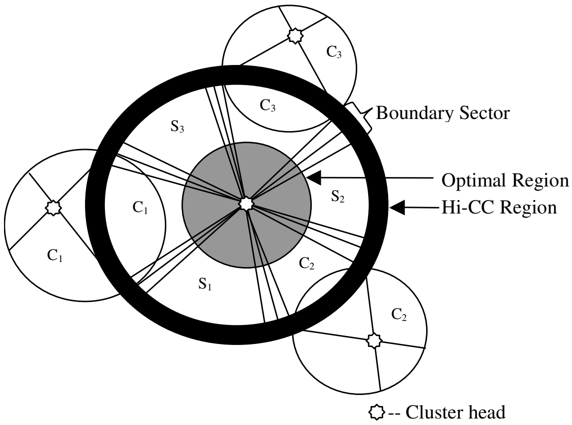

Fig. 1. The Enhanced Sectorized Cluster Structure

$$\begin{aligned}
&\text{Cluster } C \in \{C_i \mid i = 1,2...n\}, \text{ where,}\\
&\quad \text{n is the no.of adjacent clusters.}\\
&\quad \text{Each } C_i \text{ is a C - type cluster - sector.}\\
&\text{Cluster } C \in \{S_j \mid j = 1,2...N-n\}, \text{ where,}\\
&\quad S_J \text{ is a S - type cluster - sector \&}\\
&\quad \text{N is the total no.of sectors in the cluster}
\end{aligned}$$

2) Inter-Cluster (neighbouring cluster) Route Discovery:

If the source and destination nodes are in neighbouring clusters then the Request Zone will include cluster-sectors of both clusters. The determination of the request zone must take into account the number of routing packets generated as well as the mobility of the destination and cluster gateway nodes. The request zone is determined as in Fig.3. The route discovery proceeds along very similar lines to the intra-cluster route discovery scenario. However since there are two clusters involved the cluster gateway (c-gw) nodes are employed for communication between the neighbouring clusters. In cluster of S the route request message is forwarded from S in sector 2 through the optimal circle on to the c-gw node in sector 5. The optimal circle is gradually increased until a successful path to the c-gw in sector 5 is established. The forwarding nodes employ the distance rule with respect to the c-gw node and not with respect to the final destination D. The cluster head of each cluster only has knowledge of the nodes in its cluster and hence forwarding with respect to the position of D is not efficient, as it would involve inter-cluster-head messaging. From the c-gw in sector 5 of cluster S the route request is forwarded to c-gw of cluster D. Forwarding of the route request within cluster D then reduces to the intra-cluster route discovery scenario.

3) Inter-Cluster (non-neighbouring cluster) Route Discovery:

When the Source and Destination nodes are in non-neighbouring clusters a route needs to be constructed that traverses the intermediate clusters to the destination node. The request zone would include the sectors of all intermediate clusters. The request zone is determined as in Fig. 4. In cluster S and all intermediate clusters the routing request is forwarded in the optimal regions that have been defined. The size of the optimal region is increased until a path is established to the respective c-gw nodes. In cluster D the request is forwarded as in the intra-cluster route discovery scenario.

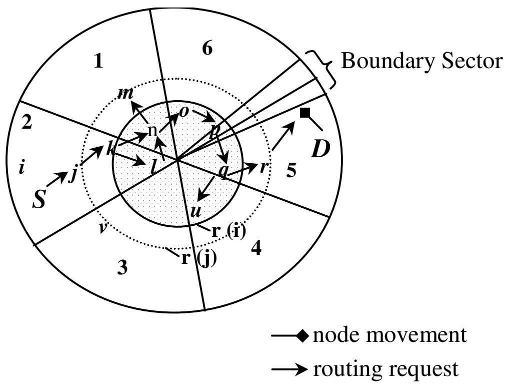

Fig. 2. Intra-cluster Route Discovery

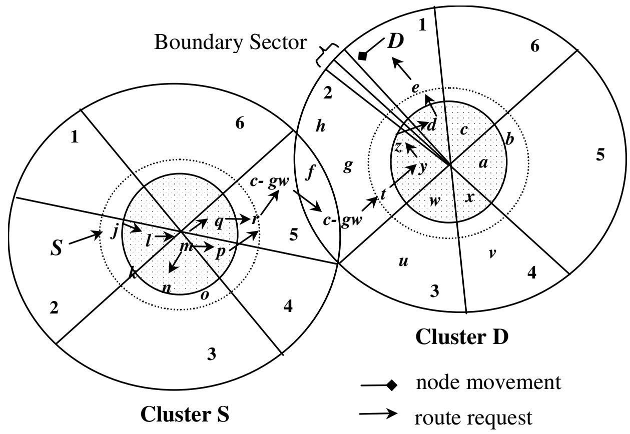

Fig. 3. Inter-Cluster (neighbouring) Route Discovery

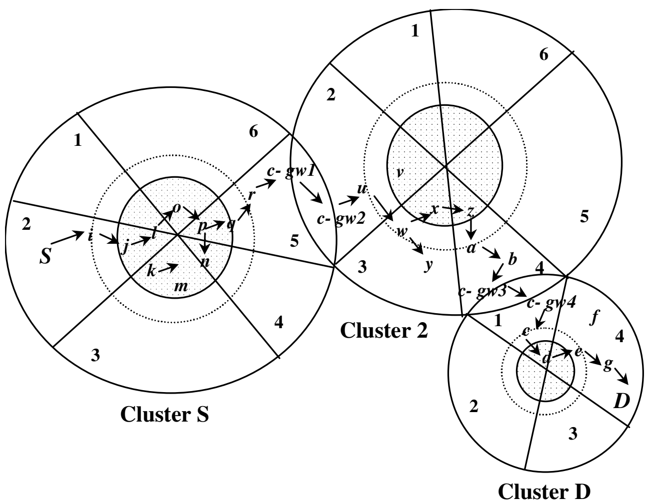

Fig. 4 Inter-Cluster (non-neighbouring cluster) Route Discovery

IV. Simulation Study of the Prediction based Location Aided Routing (P-LAR) scheme

Performance study of the proposed Prediction based Location Aided Routing scheme in an mobile ad hoc network environment was done making use of the OPNET modeler 9.0 simulation tool. The focus of the simulation study was to evaluate the performance of the proposed routing scheme in a mobile ad hoc network environment. The evaluation was to assess the efficiency of the scheme in relation to the routing overhead generated during the route discovery phase and the ratio of route discovery completion. In order for the routing scheme to be deployed in next generation networks it should exhibit route discovery completion despite randomness in user movement and introduce minimal amounts of routing overhead during the route discovery phase.

A. *Metrics of Interest*

With the above defined focus our points/metrics of interest were: -

1) Per Node Control Ratio (PNCR):

PNCR denotes the amount of routing overhead generated in the network during the route discovery phase.

$$\text{Per Node Control Ratio (PNCR)} = \frac{\text{Total amount of route discovery overhead (RRPs)}}{\text{No. of nodes per cluster x Simulation time (secs)}}$$

2) Route Discovery Completion Ratio (With Zero Re-transmit):

The Route Discovery Completion Ratio denotes the efficiency of the routing scheme with respect to route discovery.

$$\text{Route Discovery Completion Ratio (With Zero Re-transmit)} = \frac{\text{No. of Zero Re-transmit Route Discovery}}{\text{Total no. of route discovery requests}}$$

3) Cost Analysis of Route Discovery (With Zero Re-Transmit):

This denotes the cost incurred in terms of network traffic for a successful route discovery with zero re-transmits required

$$\text{Cost of Route Discovery} = \frac{\text{Route discovery overhead (RRPs)}}{\text{Route Discovery Completion Ratio}}$$

B. *Simulation Results*

The simulation model consists of a mobile ad hoc network made up of clusters of varying size. Each cluster consisted of heterogeneous mobile users with pedestrian or low-speed users (4 - 6 km/hr), medium-speed users (15 - 55 km/hr) and high-speed users (100 - 130 km/hr). The number of nodes in each cluster was varied between 20 and 120 nodes for different simulation runs. The movement of the cluster head and the mobile nodes was assumed to be an unrestricted random walk. The simulation environment allowed users to move in any direction (between 0 & 2π) and vary their speed at random intervals. Each node moves constantly without pausing in between steps. For each of the network configuration we simulated the LAR scheme 1 (Flooding algorithm), LAR scheme 2 (LAR with the distance rule), Location Trace Aided Routing (LOTAR) and the proposed P-LAR. For each simulation run, a source and a destination are chosen randomly and the source initiates a routing request to a different destination every five seconds. Each node makes multiple moves during the simulation time period with the direction of motion chosen randomly. All the nodes have the same transmission range (300m) and to maintain uniformity of results the same mobility image is retained for a specific topology across all four protocols. We assume that the cluster head of each cluster remains within the cluster during the simulation period. For each network configuration twenty simulation runs were conducted with different random seeds and the results were averaged over all these iterations. Simulation results were collected for the intra-cluster, inter-cluster (neighbouring) and inter-cluster (non-neighbouring) route discovery scenarios.

As ad hoc nodes work under strict energy constraints a reduction in the number of packets generated during the route discovery phase is required. Comparison of the per node control ratio (PNCR) is presented in Fig.5 for the intra-cluster, inter-cluster (neighbouring) scenario and inter-cluster (non-neighbouring) scenarios. A conclusion on the scalability of the routing scheme can be made by observing the variation in the control overhead ratio generated by a single node in the network. PNCR is expressed in terms of Route Request Packets per Second (RRPs/Sec). It can be observed that compared to LAR-flooding the other three methods have much lower PNCR values for all three scenarios. The PNCR values for LAR-distance, LOTAR and P-LAR in the intra cluster case remain roughly at the same level as the number of nodes in the cluster increases. This indicates that all three methods are scalable in terms of number of nodes in each cluster though P-LAR offers the lowest value of PNCR. A similar trend is observed in the neighbouring inter-cluster scenario across all four protocols but for a slight increase in the PNCR values for LAR-distance. In the case of the non-neighbouring inter-cluster scenario the observation of interest is that the PNCR values of LOTAR and P - LAR tend to decrease with the number of nodes in the cluster while there is a definite increase in the case of LAR- distance. This indicates that while the LAR-distance scheme is scalable in terms of number of nodes in a cluster it is not efficiently scalable in terms of number of clusters in the network. As the number of clusters across which route discovery needs to be performed increases the control overhead on each node in the cluster increases. The decrease in the PNCR values for LOTAR and P -LAR is attributed to the request area being limited. In order to ascertain that the saving in route discovery overhead is not at the expense of route discovery completion comparison of the route discovery completion ratio with zero retransmits was studied (The results are not presented due to space constraints). It was found that in terms of route discovery completion ratios LAR distance is best suited for sparsely populated network clusters while P-LAR and LOTAR perform best for densely populated network clusters.

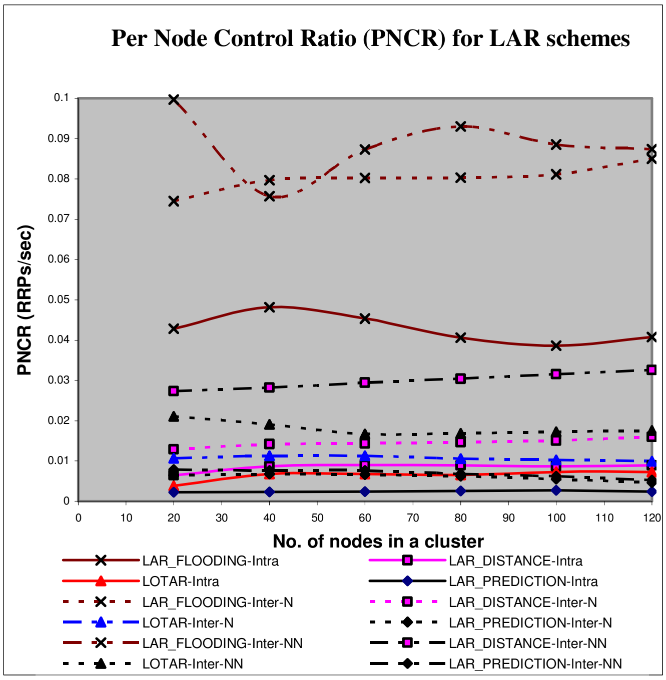

Fig. 5 Comparison of PNCR for LAR schemes

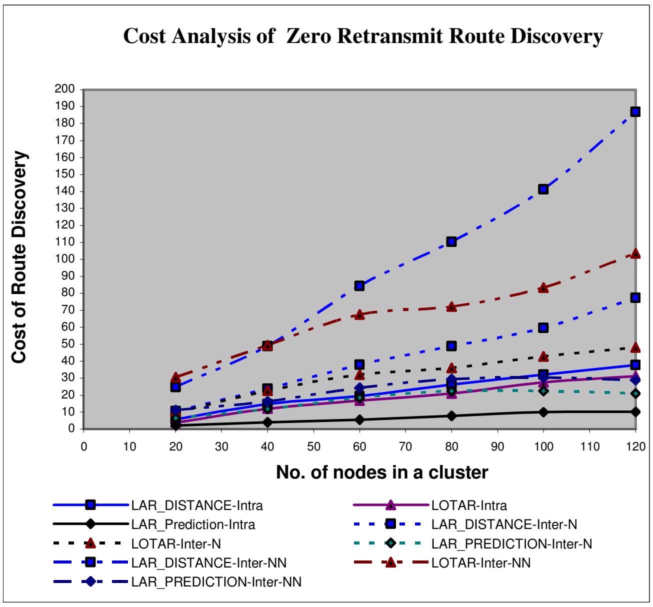

Fig. 6 Cost Analysis for Zero Retransmit Route Discovery

The cost involved in route discovery is presented in Fig.6 for the intra-cluster, neighbouring inter-cluster and the non-neighbouring inter-cluster scenarios. It is observed that for the intra-cluster and the neighbouring inter-cluster scenarios in a network with sparsely populated clusters (less than 20 nodes) the cost of route discovery is comparable. However in the non-neighbouring inter-cluster scenario the cost of route discovery is the least for P-LAR for all types of network clusters. The cost of route discovery is found to linearly increase with the population of network clusters in the case of LAR-distance and LOTAR for intra-cluster and inter-cluster route discovery scenarios. There is also a significant increase in the cost of route discovery incurred for LAR-distance and LOTAR with the number of clusters involved in the route discovery process. There is a 100% (approx.) cost increase observed in comparison between the intra-cluster and neighbouring inter-cluster scenario and in comparison between the neighbouring inter-cluster and the non-neighbouring inter-cluster scenarios for both LAR-distance and LOTAR. The cost incurred with P-LAR is at much lower levels than with the other two schemes. The cost of route discovery increasingly plateaus as the population of the network cluster increases for intra-cluster as well as inter-cluster route discovery scenarios. For moderate to densely populated network cluster in the inter-cluster route discovery scenarios there is exhibited a slight decrease in the cost of route discovery. This makes P-LAR efficiently scalable with respect to the cost of route discovery.

V. Conclusion

In this work we have introduced the Prediction based Location Aided Routing scheme aimed to reduce the search space required for route discovery and route reconstruction in mobile ad hoc networks. A method of route discovery integrating the sectorized ad hoc mobility prediction technique with the enhanced cluster-sector structure was described. Simulation of the proposed scheme was completed with OPNET modeler 9.0 with focus on the suitability of the scheme for deployment in next generation networks. Through the simulation study we evaluated the performance of the proposed routing scheme in a mobile ad hoc network and its efficiency with relation to the routing overhead generated during the route discovery phase. Cost analysis of the scheme was also completed. It is seen from the PNCR comparisons that P-LAR is much more efficiently scalable than LAR-distance or LOTAR. Evaluation of Route Reconstruction employing P-LAR is currently under study.

References

[1] S. Corson and J. Macker, " Mobile Ad Hoc Networking (MANET): Routing Protocol Performance issues and Evaluation Considerations," RFC 2501, Jan. 1999.

[2] Y. B. Ko and N. H. Vaidya, "Location Aided Routing (LAR) in Mobile Ad Hoc networks," *Proceedings of ACM/IEEE MOBICOM '98*, Oct.1998, pp. 66-75.

[3] X. Hong, K. Xu and M. Gerla, "Scalable Routing Protocols for Mobile Ad Hoc Networks," *IEEE Network*, July/August 2002, pp. 11-21.

[4] E. M. Royer, C-K. Toh, "A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks," *IEEE Personal Communications*, April 1999, pp. 46-55.

[5] J. C. Navas and T. Imielinski, "Geographic Addressing and Routing," *Proc. 3rd ACM/IEEE Intn'l. Conf. Mobile Comp. Net.* , Sept. 1997.

[6] S. Basagni et al., " A Distance Routing Effect Algorithm for Mobility (DREAM)," *ACM/IEEE Int'l. Conf. Mobile Comp. Net.*, 1998, pp. 76-84.

[7] B. Karp and H. T. Kung, "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks," *Proceedings of MobiCom2000*, pp. 243-54.

[8] Kui Wu and Janelle Harms, "Location Trace Aided Routing in Mobile Ad Hoc Networks", *ICCCN 2000*, Las Vegas, Nevada USA, October 2000.

[9] R. Chellappa, A. Jennings, N. Shenoy, "A Comparative Study of Mobility Prediction in Fixed Wireless Networks and Mobile Ad hoc Networks", Proceedings of *IEEE International Conference on Communications ICC 2003*, Anchorage, Alaska USA, May 2003.