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A REVIEW OF CURRENT MOBILITY PREDICTION TECHNIQUES FOR AD HOC NETWORKS

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ABSTRACT
Next Generation Networks (3G & beyond) will support real-time multimedia applications through traditional wide-area networking concepts as well as hot-spot (WLAN) and ad hoc networking concepts. In order to fulfil the vision of Next Generation Networks a method of maintaining a real-time flow despite frequent topology changes and irregularity in user movement is required. Mobility Prediction has been identified as having applications in the areas of link availability estimation and pro-active routing in ad hoc networks. In this work we present an overview of current mobility prediction schemes that have been proposed. Simulation results are also presented.

KEY WORDS
Ad hoc networks, Mobility Prediction.

1. Introduction

Traditional wireless and cellular networks offer a limited range of mobile communication and are constrained in their deployment by their need for underlying network infrastructure (base stations, routers etc.). Demands for increased user mobility have sparked interest in the development of an emerging class of self-organizing, rapidly deployable network architectures called Mobile Ad hoc Networks [1]. Ad hoc networks are self-organizing and self-configuring multi-hop wireless networks capable of adaptive re-configuration as effected by node mobility. Typically the network is made up of equal nodes that are equipped for wireless communication and with networking capability. Every node in the network is capable of functioning as a mobile router (maintain routes & forward packets), which makes possible the multi-hop forwarding of packets from a source node to a destination node without reliance on a fixed infrastructure. All nodes share the same random access wireless channel. With almost all development in information technology being based on wireless technology, ad hoc networks are expected to play a significant role in future communication networks where wireless access to a backbone is either ineffective or impossible.

Ad hoc network applications range from collaborative, distributed mobile computing to disaster recovery (fire, flood, earthquake), law enforcement (crowd control, search and rescue) and digital battlefield communications [2], [3]. Ad hoc networks inherit the traditional problems of wireless and mobile communications, such as bandwidth optimisation, power control and transmission quality enhancement. In addition the multi-hop nature and the lack of fixed infrastructure generate new research problems such as configuration advertising, discovery and maintenance, as well as ad-hoc addressing and self-routing. As all nodes are capable of movement and can be connected dynamically in an arbitrary manner the network topology is highly dynamic and random. A real-time flow is required to deliver data packets with strict timing requirements. To facilitate this, route discovery and route maintenance procedures should be pro-active. Reactive on-demand schemes would negatively impact real-time data traffic. If topology change can be predicted fairly accurately then route reconstruction or route discovery can be completed prior to topology change. A viable mobility prediction scheme for ad hoc networks should offer a high level of prediction accuracy with minimal control overhead.

In Section II we present mobility models that have been proposed for ad hoc networks. Section III is the leitmotif of this paper and presents in detail ad hoc mobility prediction schemes. Section IV details our simulation study and Section V concludes the work.

2. Mobility Models

The freedom from a backbone infrastructure requirement makes mobile ad hoc networks a more flexible communication model than cellular networks. The increased mobility of ad hoc nodes, however, presents a challenging issue for protocol design. Ad hoc protocols must exhibit robustness and adaptability to frequent changes in network topology. In order to better understand and quantify mathematically the mobility of ad hoc network nodes, several mobility models as in Fig.1 have been proposed in literature.

The Random Walk model [4] defines user movement from one position to the next with memoryless randomly selected speed and direction. The Random Waypoint model [5] derived from the random walk model breaks down the entire movement of the user into a series of pause and motion periods. The user stays at a particular location for a specified time period before moving on to the next in a randomly chosen direction with speed uniformly distributed between [0, MaxSpeed]. Based on the Markovian model for random motion an incremental model [6] is presented in which speed and direction of current movement randomly diverge from the previous values of speed and direction after each time increment. Speed ν and direction θ are expressed as:

$$v(t+\Delta t) = \min\left[\max(v(t)+\Delta v, 0), V_{\max}\right] \tag{1}$$

$$\theta(t+\Delta t) = \theta(t) + \Delta\theta \tag{2}$$

where Δv and $\Delta\theta$ are uniformly picked up from a predefined data range of $[-A_{\max}\Delta t, A_{\max}\Delta t]$ and $[-\alpha\,\Delta t, \alpha\,\Delta t]$. A_{max} is the unit acceleration/deceleration and α is the maximal unit angular change.

Ad hoc networks are usually deployed for a common goal to be achieved (e.g., disaster relief or search and rescue). The movement of nodes could therefore exhibit collective or group mobility characteristics. The Pursue model and the Column model [7] study the relationship between mobile nodes, in disaster recovery and military situations where mobile nodes tend to move with a common objective (as a column) or follow (as in pursue) other nodes. The Reference Point Group Mobility (RPGM) model [8] uses the mobility of the logical centre of each group to define the behaviour of the entire group. Each node is assigned a reference point relative to its position with that of the group's centre. The group motion vector maps out the location of the reference centre which when added to the node dependent random motion vectors gives the position of the nodes. The displacement of a mobile node from its reference point gives its individual random motion component. The Reference Velocity Group Mobility (RVGM) [9] model further extends the RPGM model by proposing a velocity representation of the mobility groups and mobile nodes, and is the time derivative of the displacement based group representation. Each mobility group has a characteristic group velocity that is closely matched by each of the member nodes with small deviations. Analogous to the RPGM model the characteristic group velocity serves as the reference velocity for the nodes.

Ad hoc networks can also be heterogeneous in nature with different nodes exhibiting varied mobility patterns. The Mobility Vector [10] model offers a flexible mobility framework for hybrid motion patterns. The model allows for partial changes in the mobility state of a node by "remembering" the mobility state. A mobility vector expresses the mobility of a node as the sum of two sub vectors: the Base Vector $\vec{B} = (bx_v, by_v)$ and the Deviation vector $\vec{V} = (vx_v, vy_v)$. The base vector defines the major direction and speed of the node while the deviation vector stores the mobility deviation from the base vector. The mobility vector is expressed as $\vec{M} = \vec{B} + \alpha\vec{V}$ where α is an acceleration factor

3. Mobility Prediction in Mobile Ad hoc Networks

The motivation behind the mobility models has been the potential of mobility prediction for application in various fields of ad hoc networking as in Fig.2. The application and critical study of various mobility prediction schemes has shown mobility prediction to offer potential improvements to both the service-oriented (where nodes co-operate to facilitate general communication e.g., routing) and application-oriented (where nodes come together for a particular purpose e.g., military operations) aspects of ad hoc networks.

3.1 Mobility Prediction for enhanced routing and link availability estimation

A prediction mechanism for link expiration time (LET) between any two ad hoc nodes has been observed [11] to enhance various unicast and multicast ad hoc routing protocols. It is proposed that by exploiting the non-random movement patterns of a user we can predict the future state of the network topology providing transparent access during the time of topology change. By piggybacking GPS based position information on data packets the link expiration time between any two nodes is estimated. If two nodes node *i* and node *j* at positions (x_i, y_i) and (x_j, y_j) are travelling at speeds v_i and v_j with moving directions θ_i and θ_j respectively with a transmission range *r* then the time period D_t during which they would stay connected is predicted as: -

$$D_t = \frac{-(ab+cd) + \sqrt{(a^2+c^2)r^2 - (ad-bc)^2}}{a^2+c^2} \tag{3}$$

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

By predicting the LETs of all links of a route the Route Expiration Time is given as the least of the LET values. This enables route reconstruction to take place prior to route failure. Reported results show that unicast protocols using mobility prediction such as the Flow Oriented Routing Protocol (FORP) [12] and Distance Vector with mobility prediction (DV-MP) [16] were the least affected by mobility maintaining delivery ratios of 0.9 for speeds of up to 70 km/hr. The On-Demand Multicast Routing Protocol with mobility prediction (ODMRP-MP) [12] performs better than its counterpart without mobility prediction offering a delivery ratio of 0.9 (i.e., 10% of packet loss) up to speeds of 70km/hr. The proposed method offers accurate prediction support to networks with simple mobility patterns with no sudden change in direction and constant speed. Since ad hoc networks find application in environments that prompt sudden changes in speed and direction of user movement, the assumption of constant user speed and direction is problematic for most scenarios in an ad hoc network [2].

The proximity model [1] aims to quantify the future proximity of adjacent nodes and provides a quantitative metric that reflects the future stability of a given link. The model minimizes the requirement for precise mobility information and computes the initial baseline link availability assuming random independent mobility. The model adapts future computations depending on the expected time-to-failure of the link, based on the independence assumption and a metric that reflects the environment. The relative movement of any two nodes may be independent or correlated. The total link availability between two nodes m and n is expressed as: -

$$A_{m.n}^{T}(t) = A_{m,n}^{i}(t)P_i + A_{m,n}^{c}(t)(1 - P_i) \quad (4)$$

where $A_{m.n}^{T}(t)$ is total link availability, $A_{m,n}^{i}(t)$ is the availability when mobility is independent and $A_{m,n}^{c}(t)$ is the availability when mobility is correlated. The metric reflects independent or correlated behaviour as given by the value of P_i. A value of $P_i = 1$ reflects independent movement with respect to the total link availability. The idea is to initially assume that the endpoints of a link are moving independently and to evaluate the link availability based on the independent model $A_{m,n}^{i}(t)$. Any link that survives more than the predicted time to failure gradually transitions to the correlated model $A_{m,n}^{c}(t)$ based upon a smoothing exponential function. The rate of the function depends on the time elapsed since the expected time to failure and the magnitude of the independent mode availability. The model in comparison to the LET scheme better defines the mobility in an ad hoc environment by incorporating random independent mobility into the link stability metric. With proper specification of P_i, the proximity model can achieve benefits through the detection of associated movement patterns; however it is not possible to detect negative correlation patterns without the availability of apriori information.

The Sectorized ad hoc mobility prediction scheme [17] is built on the rationale that in order to achieve maximum accuracy in movement prediction the prediction process should be restricted to areas of high cluster change probability. To ensure prediction accuracy the process must guard against under-prediction (i.e., commencing the prediction process too late so as to miss a cluster change) and over-prediction (i.e., predict too early along a user path). Prediction restricted to the last movement legs of a mobile user ensures higher accuracy of prediction. The sectorized cluster structure based on cluster change probability is introduced to aid in mobility prediction. The sectorized ad hoc mobility prediction scheme makes use of the cluster-sector numbering scheme to predict user movements in an ad hoc network. As the topology of the ad hoc network is dynamic, prediction of user movements from mobility history bases (MHB's) is not possible and/or efficient. Hence MHB's are not employed for prediction purposes in mobile ad hoc networks.

In a cluster based ad hoc network the location of the user is defined with respect to its position with that of the cluster head. The cluster head has complete knowledge of each of its member nodes. Assuming a circular cluster structure as shown in Fig. 3 there is a region of the cluster in which all the nodes belonging to the cluster are in closest proximity to each other. All nodes in this region of the cluster are within communication range of each other. This region is defined as the NO-Cluster change or No-CC region. The reasoning is that nodes in this region of the cluster will not satisfy the requirements for membership to any of the neighbouring clusters. As a result cluster change from this region is not possible. There exists a region in each cluster that is defined as the Low-Cluster change or Low-CC region as the probability of cluster change from this region is fairly low. There also exists a region in every cluster where the nodes in this region are not reachable by any of the nodes in the No-CC region either directly or through other intermediate nodes belonging to the No-CC region. These outlying nodes are reachable only through the nodes in the Low-CC region. This region is defined as the High-Cluster change or Hi-CC region as the probability of cluster change for nodes in this region is higher than for nodes in the No-CC or Low-CC regions. Based on the above observations a novel method of cluster division that makes possible accurate mobility prediction with sufficient reduction in the required area of tracking is proposed. The cluster is further divided into sectors as in Fig. 3. Two types of sectors are introduced depending on whether or not the sector is adjacent to a neighbouring cluster. C-type cluster-sectors C_1, C_2, C_3 have as neighbours, clusters that are accessible through their cluster gateway nodes. It is only from C-type clusters that cluster change is possible. Each C-type cluster is adjacent to only one neighbouring cluster and it is only to this cluster that the user can cluster change to. Nodes in S-type cluster-sectors S_1, S_2, S_3 are not candidates for cluster change as there are no adjacent clusters present. For the purpose of positioning GPS or any other localization technique may be employed.

The cluster sector-numbering scheme is used to predict the next cluster change depending on the user's current cluster and direction of travel in the Hi-CC region. 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. The Cluster-Sector numbering scheme is as in Fig. 4. The numbering scheme is only for prediction purposes and sits on top of any other cluster numbering scheme that may be in use.

The user's current cluster is always identified as the reference cluster 0, i.e., if the user moves from cluster 0 in the figure to cluster 5 then cluster 5 becomes cluster 0 for mobility prediction purposes. Each C-type cluster-sector of the resident cluster is then identified using $0_j|a$ where

‘0’ is the reference cluster and ‘a’ denotes the neighbouring cluster to which the user can cluster change to from this particular sector of the reference cluster. An adjacent sector of $0_j|a$ is referenced as $a_1|0$. Re-referencing of a neighbour cluster is only done if the distance from the original reference cluster sector to the present resident sector is at the least 2 cluster-sector crossings. The system is robust enough to handle oscillating users between two sectors of neighbouring clusters without any re-referencing.

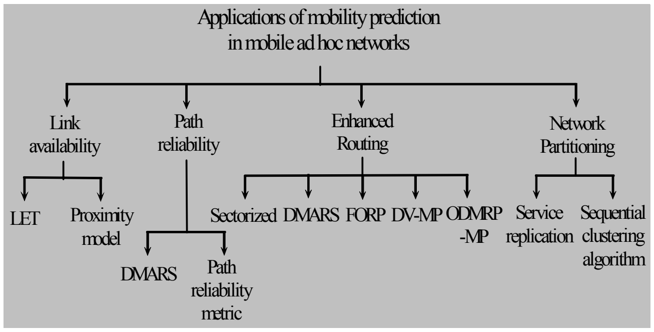


Fig.1 Applications of Mobility Prediction in MANETs.

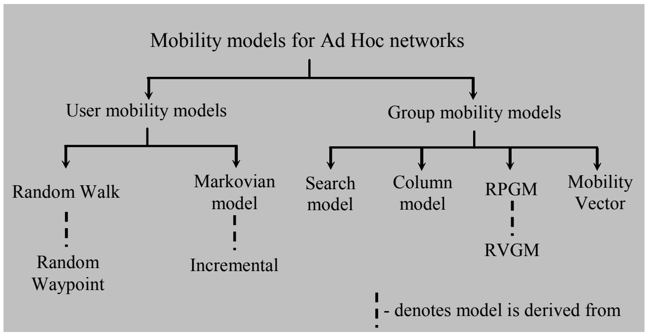
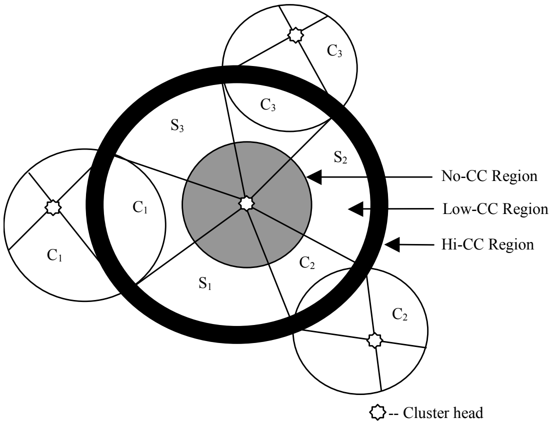


Fig.2. Summary of Mobility Models for Ad hoc Networks



Cluster $C \in \{C_i \mid i = 1,2...n\}$, where,

n is the no.of adjacent clusters.

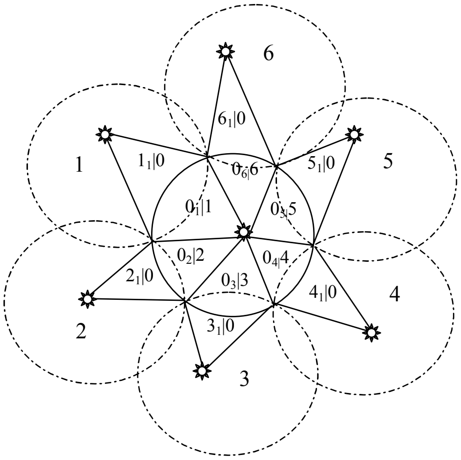
Each C_i is a C - type cluster - sector.

Cluster $C \in \{S_j \mid j = 1,2...N - n\}$, where,

S_j is a S - type cluster - sector &

N is the total no.of sectors in the cluster.

Fig. 3. The Sectorized Cluster Structure



Definition :

Each C - type sector of cluster 0 takes a value $0_j \mid i$

where $i = 1,2,...n$

j = total no.of sectors in Cluster 0

n = no.of adjacent clusters of 0

An adjacent sector takes the value $i_1 \mid 0$

Fig. 4. Cluster-Sector Numbering scheme

The advantage of the sector-by-sector tracking method is that the number of possible cluster change points can be brought down to 1 (the cluster with which the current cluster sector shares an edge) or at the very least to 3 (the cluster with the common edge and the 2 clusters that share vertices with the current cluster-sector). This method of sector numbering ensures this upper bound on the number of cluster change points irrespective of the total number of neighbouring clusters. It is therefore efficient for ad hoc networks with both low and high levels of clustering. The accuracy of the scheme is however dependant on the accurate classification of users.

3.2 Mobility Prediction for path reliability estimation

Prediction based link availability [14] proposes a metric for path selection based on path reliability. The method first allows a node to predict a continuous time period T_p during which a currently available link would last from t_o assuming that both nodes of the link would keep their current movements unchanged in terms of both speed and direction. Then the probability that the link will last to $t_o + T_p$, $L(T_p)$ is estimated by calculating possible changes in the nodes' movements that might occur between t_o and $t_o + T_p$. The link availability estimation consists of ‘unaffected T_p’ with node movements being unchanged and ‘affected T_p’ with node movements being changed. Assuming that the mobility epoch (a random length interval during which node movement is unchanged) is exponentially distributed with mean λ^{-1} and node mobility is uncorrelated, link availability is given as,

$$L(T_p) = L_1(T_p) + L_2(T_p) \tag{5}$$

where $L_1(T_p)$ is the link availability estimation for the unaffected case and $L_2(T_p)$ is the estimate for the affected case. Since the node movements are independent of each other and the exponential distribution is memoryless, $L_1(T_p)$ is given as: -

$$\begin{aligned} L_1(T_p) &= [1 - E(T_p)]^2 \\ &= e^{-2\lambda T_P} \end{aligned} \tag{6}$$

An accurate calculation of $L_2(T_p)$ is challenging due to the difficulties in learning the changes in link status caused due to node mobility. A conservative prediction of link availability $L_{\min}(T_p)$ is proposed.

$$L_{\min}(T_p) = \frac{1 - e^{-2\lambda T_P}}{2\,\lambda\, T_p} + \frac{\lambda\, T_P e^{-2\lambda T_p}}{2} \tag{7}$$

Based on the above estimation a routing metric based on $L(T_p)\ T_p$ is proposed. Reported results show it to offer improved network performance in terms of network loss, delay and goodput. In highly volatile environments it is possible that the mobility epochs (during which the mobility of the user is unchanged) can be very small. This will necessitate a large number of estimations increasing the control overhead. Also the accuracy of the link availability prediction requires that the original estimation of T_p by the nodes is accurate.

Distributed Mobility Aware Route Selection (DMARS) [15] aims to improve existing unicast routing protocols using mobility prediction. A mobility metric that exploits the non-random behaviours in user mobility patterns, to select more stable routes and reduce routing overhead is presented. A probabilistic prediction mechanism that makes use of location information is proposed for the ad hoc mobility model in which a user is assumed to move in a straight line to its destination with constant velocity. It is assumed that if a node does not change its neighbour vector drastically during the interval $t_0 - t$ to t_0, it will not change its neighbour vector during the interval t_0 to $t_0 + t$ with probability $(p_0 + \alpha)$ where α is unit increment change in probability. On the other hand if a node changes its neighbour vector drastically during the interval $t_0 - t$ to t_0, it will not change its neighbour vector during the interval t_0 to $t_0 + t$ with probability $(p_0 - \beta)$ where β is unit reduction in probability and p_0 is the current probability that the node will not change its neighbour vector drastically. The unit reduction in probability is kept much higher than the unit increment in probability as the change in topology has a telling effect on the stability of routes. In order to characterise the availability of links between any two neighbours during the interval $(t_0, t_0 + t)$, a vector is defined to calculate the individual mobility of a node in isolation. Reported results of the scheme show it to offer improved performance with reduction of route breaks, fraction of packets dropped and overhead generated for mobility speeds of up to 80 km/hr. The main weakness of the prediction mechanism lies in the assumption that the mobile user moves to its destination in a straight line with constant velocity (contrary to most ad hoc mobility models), which is restrictive.

3.3 Network partition prediction in mobile ad hoc networks

In wireless ad hoc networks, network partitioning occurs when mobile nodes moving with diverse mobility patterns cause the network to separate into two disconnected entities. As global scale changes in topology are attributed to group mobility a method of partition prediction [9] that exploits group mobility patterns is proposed. If the network consists of two mobility groups C_j and C_k each moving at velocities W_j and W_k the relative mobility is obtained by fixing one group stationary. Then the effective velocity W_{jk} at which C_k is moving away from C_j is given as: -

$$W_{jk} = W_k + (-W_j) \tag{8}$$

Assuming that all groups have a circular coverage region of diameter D wherein the nodes are uniformly distributed and are in perfect overlap, C_k must move past a distance of the diameter D of C_j's coverage area. Hence the time taken for the two groups to change from total overlap to complete separation is given as: -

$$T_{jk} = \frac{D}{\sqrt{w_{jk,x}^2 + w_{jk,y}^2}} \tag{9}$$

where $W_{jk} = (w_{jk,x} + w_{jk,y})$.

In a network made up of diverse mobility groups given the mean group velocities the time of separation can be calculated for any pair of mobility groups. The occurrence of partitioning is predicted as a sequence of expected time of separations T_{jk} between the various mobility groups in the network. The partition prediction method employed in a clustering algorithm exhibits perfect accuracy of node classification; however group and node velocities are considered to be time invariant, which is not typical of ad hoc networks.

4. Simulation Study

Simulation study of the proposed mobility prediction techniques was completed using OPNET modeler 9.0. The focus of the study was to evaluate the performance of the algorithm in an ad hoc network environment. The evaluation was to assess cluster change prediction accuracy and the amount of control overhead introduced by the prediction process. An efficient scheme should exhibit high prediction accuracy despite randomness in user movement and introduce minimal amounts of control traffic on the wireless link. With this focus our points/metrics of interest were: -

- Ratio of control overhead: The ratio of the control traffic introduced into the wireless link by the prediction process to the total data traffic on the wireless link.

$$\text{Ratio of Control overhead} = \frac{\text{Amount of prediction related control traffic}}{\text{Total Amount of data traffic}}$$

- Prediction Accuracy: The ratio of the number of cluster changes predicted and actually executed by the user to the number of cluster changes predicted by the scheme.

$$\text{Prediction Accuracy} = \frac{\sum_{i=1}^{n} \frac{\text{No. of user}_{\text{i}} \text{ executed cluster changes}}{\text{(No. of predicted) user}_{\text{i}} \text{ cluster changes}}}{\text{Total number of users in the network}}$$

$$where\ i = 1 \ldots n$$

$$n \text{ is the total number of users in the network}$$

- User Mobility Support: The scheme should be able to support different user types with the same level of prediction accuracy and control overhead.

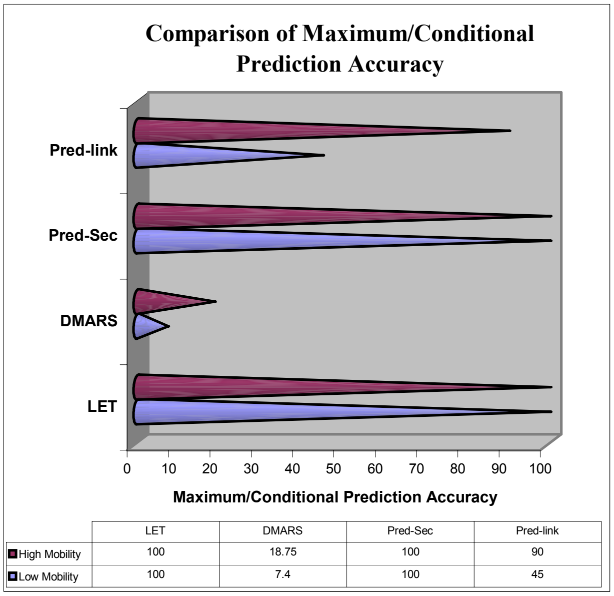
The simulation model consists of a cluster based mobile ad hoc network. The movement of the cluster head in each cluster is restricted to always remain within the cluster. In order to maintain consistency of results and ensure that all clusters have equal cluster change probabilities, user executed cluster changes from outlying clusters are not included in the simulation results. To maximize the number of cluster changes executed on the network each mobile user was assumed to maintain a call for the entire simulation interval. The movement of the mobile user was not restricted in relation to direction or step size. The simulation environment allows users to move in any arbitrary direction (between 0 & 2π) and vary their speed at random intervals. Depending on the user category there exists [MinSpeed, MaxSpeed]. Simulation runs were conducted for pedestrian or low-speed users with a speed of 4 km/hr - 6 km/hr, medium-speed users with a speed of 15 km/hr - 55 km/hr and, high-speed users of speed 100 km/hr - 130 km/hr. The diameter of each cluster was set approximately to 500 meters. Simulation runs were conducted with different random seeds and the results were averaged over all these iterations.

Work on mobility prediction schemes in ad hoc networks has primarily been focussed on link availability estimation between any two mobile ad hoc nodes. Estimation schemes for link availability between any two ad hoc nodes have been proposed to reduce the routing overhead incurred due to ad hoc mobility [14], [15], [16]. To the best of our knowledge the sectorized mobility prediction scheme (Pred-Sec) is the only scheme addressing cluster change predictions in ad hoc networks. Fig.5 gives the comparative plot of the maximum/conditional accuracy possible by various ad hoc mobility prediction schemes. The prediction based link availability estimation [14] is found to be 80-90% accurate in high mobility environments and 40-50% accurate in low mobility environments while DMARS is found to offer low levels of accuracy in both low and high mobility environments. LET and our sectorized prediction scheme are capable of high levels of prediction accuracy in both low and high mobility environments. While the prediction accuracy of LET is dependent on the accuracy of GPS data, Pred-Sec requires accurate definition of the High-CC region. While a high level of prediction accuracy is desirable, the control overhead incurred by the prediction process will be detrimental to the viability of the prediction scheme in an ad hoc network.

Fig.6 gives a comparative plot of the control overhead introduced by DMARS, LET and the Sectorized Prediction techniques. DMARS offers considerable reduction in the number of route breaks in both medium and high mobility ad hoc networks. However the control overhead incurred for this improvement in route stability is at least 1(i.e., 1 control packet per data packet) in low mobility and increases up to 2.5 (i.e., 2.5 control packets per data packet) in high mobility. The time of link expiry in LET is calculated based on GPS data. Assuming 100% accuracy of GPS data the control overhead incurred is 7.1 for low mobility and 7.8 in high mobility. Which is quite significant for wireless links and in particular energy constrained ad hoc nodes as the reception, transmission and the processing of packets can all consume energy. As the deviation in the accuracy of GPS data increases the control overhead is found to gradually increase. While the control traffic introduced by DMARS and LET are greater than the data traffic delivered Pred-Sec is found to introduce minimal amounts of control overhead on the wireless link.

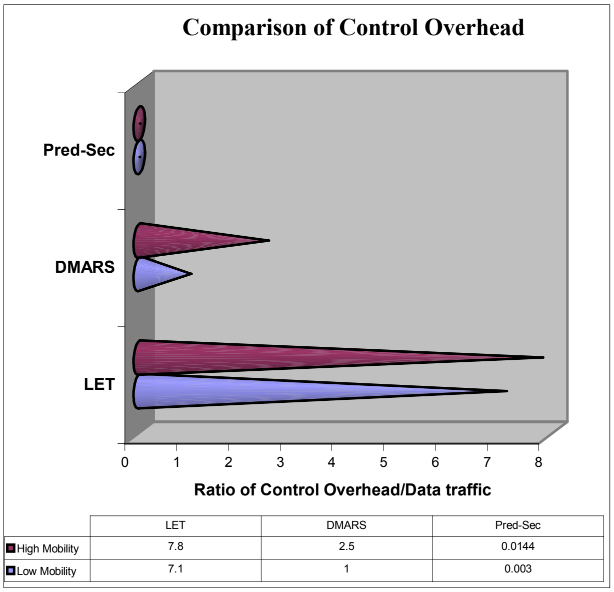
5. Conclusion

The vision of next generation networks requires that real-time multimedia applications be supported in a heterogeneous networking environment. Service continuity is to be guaranteed despite increased freedom in the mobility of the user. Mobility prediction has been identified as a facilitator of this vision and in this article we have presented a review of current work in mobility prediction for ad hoc networks. It has been seen that the sectorized method of mobility prediction compares favourably in terms of prediction accuracy and control overhead with other methods of mobility prediction. Results of our simulation study to this effect have been presented.



	LET	DMARS	Pred-Sec	Pred-link
■ High Mobility	100	18.75	100	90
■ Low Mobility	100	7.4	100	45

Fig. 5. Comparison of Prediction Accuracy



	LET	DMARS	Pred-Sec
■ High Mobility	7.8	2.5	0.0144
■ Low Mobility	7.1	1	0.003

Fig. 6. Comparison of Control Overhead

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