User Mobility Prediction in Hybrid and Ad Hoc Wireless Networks

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Abstract – Next Generation Networks will employ hybrid network architectures using both cellular and ad hoc networking concepts. The vision of real-time multimedia services requires that mobility management be addressed in a proactive manner. If the user movements can be predicted accurately in a hybrid network environment then handoff/cluster change, resource reservation and context transfer procedures can be efficiently completed as required by node mobility. In this work we propose a sectorized ad hoc mobility prediction scheme for cluster change prediction. Simulation study of the scheme shows it to be efficient in terms of prediction accuracy and prediction related control overhead despite randomness in user movement.

I. INTRODUCTION

The vision of Next Generation Networks (4G and beyond) is to offer real-time multimedia services such as high-performance wireless teleconferencing, video conferencing and full motion video by supporting high-speed transport. While 3G networks are based primarily on the wide area cell-based concept, 4G networks will essentially be hybrid networks that make use of cell or base station based wide area network design along with ad hoc networking and hot-spot (wireless LAN) concepts. An Ad hoc network is a self-configuring and self-organizing multi-hop network of equal nodes (mobile routers). 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. 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.

In order for a prediction scheme deployed in existing 2G/3G networks to smoothly transition to future 4G technologies it needs to be efficient in both infrastructure supported (cellular) and infrastructure-less (ad hoc) environments. The prediction algorithm should not be sensitive to randomness in user movement patterns, as 4G networks are required to support global mobility. 4G networks are also envisioned as networks offering seamless and heterogeneous mobility which requires a potential 4G mobility prediction scheme to be non-technology specific. A viable prediction scheme for a hybrid/ad hoc network should offer a high level of prediction accuracy while incurring minimal amounts of control overhead. Related work is presented in Section II with the sectorized ad hoc mobility prediction scheme in Section III. Simulation study is presented in Section IV with the conclusion in Section V.

II. RELATED WORK

Most cellular mobility prediction schemes make use of a history base that has a record of the previous user movements. These algorithms make use of the history base and by taking into account the respective probability of movements together with factors such as the direction of motion and the velocity; regular movements of users can be predicted fairly accurately. However with the introduction of even the smallest degree of random variation, traditional algorithms that predict based on the location criterion, direction criterion, segment criterion, time criterion or Baye's rule fail [1]. Their failure is attributed to an inability to adapt efficiently with the changes in user behaviour. The Mobile Motion Prediction (MMP) algorithm [2] and The Regular Path Recognition Method [3] attempt to exploit regularity in human behaviour in terms of periodic or repetitive activities. Although the performance of these algorithms is accurate with regular movement patterns accurate prediction of random movements is not addressed. The Shadow cluster concept [4] again makes use of the user's movement history to create a shadow of the user's future positions and advocates probabilistically reserving resources along the possible path. The drawback is that resource reservation can be overly aggressive causing an increased blocking of new calls.

Ad hoc networks find applications mostly in hostile military environments or in emergency search and rescue operations. As a result prediction of future movements based on the past history is not viable due to the dynamic topology and the dissimilar requirements of the situation. Work on mobility prediction schemes in ad hoc networks has primarily been focussed on link availability estimation between any two mobile ad hoc nodes. Su et al. [5], predict the link expiration time between any two nodes in an ad hoc network by making use of the co-ordinates of the nodes, their speeds and direction of motion. Wang et al. [6], introduce a group mobility model for service replication and partition prediction. However they assume velocity to be time invariant which is not typical of an ad hoc network.

III. THE SECTORIZED AD HOC MOBILITY PREDICTION ALGORITHM

In order to define a semblance of grouping in ad hoc networks clustering has been proposed. Every node in the network belongs to a cluster and will change its cluster of membership as effected by mobility. The proposed prediction scheme is built on the rationale that in order to achieve maximum prediction accuracy 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. To this end we introduce the sectorized cluster structure based on cluster change probability to aid in mobility prediction. The sectorized ad hoc mobility prediction scheme introduces the sectorized cluster structure and makes use of the cluster-sector numbering scheme to predict user movements in an ad hoc network. Due to the dynamic topology of an ad hoc network, prediction of user movements from mobility history bases is not possible and/or efficient. Hence MHB's are not employed for prediction purposes in a purely ad hoc network.

For mobility prediction in the fixed (cellular) part of the hybrid network we make use of the sectorized mobility prediction scheme [7].

A. The Sectorized Cluster Structure

In cluster based ad hoc networks we seek to define the location of the user with respect to its position with that of the cluster head. The cluster head has complete knowledge of each of its member nodes. If we assume a circular cluster structure as shown in Fig. 1 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. We define this region 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 every cluster where the nodes in this region are reachable by all of the nodes in the No-CC region either directly or through other intermediate nodes belonging to the No-CC region. We define this region of the cluster 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. We define this region of the cluster 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 we suggest a novel method of cluster division that makes possible accurate mobility prediction with sufficient reduction in the required area of tracking. The cluster is divided into three regions with respect to probability of cluster change as No-CC, Low-CC and High-CC regions.

Depending on the algorithm employed for clusterhead election the No-CC region may or may not be centred on the clusterhead. The definition of these regions can be user specific or network specific. User specific definition of the No-CC and Low-CC regions can ensure that highly mobile users have a larger Hi-CC region than users of lesser mobility. The cluster is further divided into sectors as in Fig.1. 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.

B. Cluster-Sector Numbering scheme for user movement prediction

In cellular networks it is possible to predict regular user movements based on a mobility history base (MHB). This is not feasible in an ad hoc network as the movements of users are varying and dependent on the current purpose of the network. They do not follow regular day-to-day paths. While it is possible to obtain accurate tracking by making the prediction process highly complex the proposed method is computationally non-intensive and introduces minimal amounts of additional traffic on the wireless link. The cluster sector-numbering scheme is able 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. 2. The numbering scheme is only for prediction purposes and sits on top of any other cluster numbering scheme that may be in use.

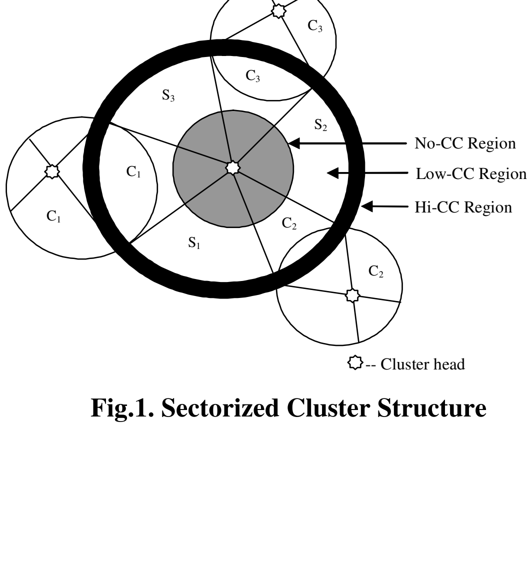

Fig.1. Sectorized Cluster Structure

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

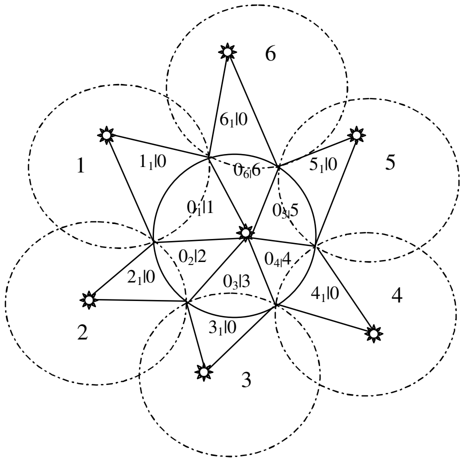

Fig. 2. The Cluster Sector Numbering Scheme

> ***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 $i_1 \mid 0$

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.

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. In the example in Fig. 2 there results a two-fold decrease in the sample space. As the number of neighbouring clusters increases the degree of reduction in the sample space will increase. This decrease in the number of possible cluster change points contained in the sample space will increase the probability of an accurate prediction.

IV. Simulation Study of the Sectorized Ad hoc Mobility Prediction scheme

A performance study of the proposed sectorized ad hoc mobility prediction scheme in a hybrid/ad hoc environment was completed using OPNET modeler 9.0 simulation tool. The focus of the simulation study was to evaluate the performance of the sectorized approach to mobility prediction in hybrid and purely ad hoc network environments. The evaluation was to assess cluster change prediction accuracy, sensitivity of the prediction scheme to randomness in user movement and the amount of control overhead introduced by the prediction process. The 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: -

- Prediction Accuracy: The ratio of the number of cluster changes actually executed by the user to the number of cluster changes predicted by the scheme. To be incorporated successfully into a resource reservation scheme the prediction process should guard against over-prediction.

$$\text{Prediction Accuracy} = \frac{\sum_{i=1}^{n} \dfrac{\text{No. of user}_i \text{ executed cluster changes}}{\text{No. of predicted user}_i \text{ cluster changes}}}{\text{Total number of users in the network}}$$
$$where\ i = 1...n$$
$$n \text{ is the total number of users in the network}$$

- Randomness Factor (R_f): The randomness factor in a hybrid network is the average of the randomness factors in each of the distinct networks. The randomness factor of a purely ad hoc network is 1, as mobility history bases to store the "regular" movements of the nodes cannot be employed due to the dynamic topology.

$$\text{Randomness Factor for Hybrid network } (\text{R}_{\text{Hybrid}})$$
$$= Average(\text{R}_{\text{Fixed}} + \text{R}_{\text{Ad hoc}})$$
$$\text{where, R}_{\text{Adhoc}} = 1.$$

- 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.

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

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

A. *Simulation Environment*

The simulation model consists of a hybrid network made up of hexagonal cells for the fixed network and clusters for the ad hoc network. While the base station for each cell resides in the centre of the cell the cluster head of each of the clusters may or may not. We restrict the movement of the clusterheads such that they always remain in the cluster. In order to maintain consistency of results and ensure that all cells have equal handoff probabilities user executed handoffs from outlying cells are not included in the simulation results. To maximize the number of handoffs/cluster changes executed on the network each mobile user was assumed to maintain a call for the entire simulation interval. Seamless mobility of the user is assumed between the fixed and the ad hoc parts of the network. The movement of the mobile user was not restricted in relation to direction or step size. The simulation environment allowed users to move in any arbitrary direction (between 0 & 2π) and vary their speed in 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 cell and cluster were set approximately to 1000 meters. Simulation runs were conducted with different random seeds and the results were averaged over all these iterations.

B. *Simulation Results*

Fig. 4 shows the Prediction accuracy Vs. Tracking Area results for all three types of users with a randomness factor of $R_{Hybrid} = 0.6$. As R_{Hybrid} = Average (R_{fixed} +$R_{Ad\ hoc}$) this implies that $R_{fixed} = 0.2$. This implies that 80% of all handoffs have been recorded in the MHB and only the remaining 20% are to be predicted. As $R_{Ad\ hoc}$ is always 1, the cluster-sector numbering scheme is employed for all user movement prediction in the ad hoc part of the network. In a hybrid network with just one fixed and one ad hoc part the prediction accuracy is thus 40% even when the numbering schemes are not employed for the prediction of random movements. It is observed that there exists a critical value of the total area of tracking in the network region for which there is maximum prediction accuracy (100%).

For a randomness factor of 0.6, perfect prediction accuracy is achieved for all three types of users. However this is dependant on the size of the network tracking area. It is observed that the size of the tracking region (for accuracy) is increasing as the speed of the user increases. As users of lower speeds tend to make more number of movements in the High-HO and High-CC regions the area of tracking has to be reduced to enable prediction as late as possible. Fast moving users on the other hand have to be tracked for a minimum time before a prediction can be made and this requires a larger tracking region than a slower moving user. As the tracking area is increased beyond the critical area the accuracy of prediction is found to decrease. There is inaccuracy introduced in the system as a result of over-prediction occurring once the tracking area increases beyond the maximum accuracy level. Results obtained for Prediction Accuracy Vs. Tracking Area for higher R_{Hybrid} value of 0.8 is reported in Fig. 5.

Fig. 6 reports the results for Prediction Accuracy Vs. Tracking area for user movement randomness value $R_{Hybrid} = 1$. It is observed that the scheme is capable of accurate prediction in the completely random movements scenario with critical areas of tracking being 22.25%, 28% and 34.14% of the total network area for the slow moving, medium-speed and high-speed users respectively. The scheme by offering maximum accuracy independent of MHB's is capable of functioning even in the event of MHB failures without the requirement of a proactive restoration scheme being in place. The reduction in the area of tracking augurs well for the scheme in comparison to traditional schemes that require tracking in the complete network area.

Fig. 7 reports Tracking region Vs. Control overhead for the three different user speeds for $R_{Ad\ hoc}$=1. It can be seen that the control overhead introduced by the prediction mechanism is found to increase as the area of tracking is increased. The dotted lines in the plot indicate the maximum accuracy or critical size of the High-CC region for the different user speeds and their corresponding control overhead. As expected the control overhead is proportional to the user speed. The slowest moving user introduces the lowest amount of control traffic and the highest speed user the most. The observed results indicate that the control over head for a low speed and medium speed user is around 0.5% while for a high-speed user (100-130 Km/hr) the control overhead for maximum accuracy is around 1.44%. The scheme introduces minimal amounts of control traffic even for tracking in the complete network area. A user requiring tracking in complete network (cluster/cell) area because of its speed of travel would still introduce less that 10% of control overhead in the network. The scheme is thus especially suitable for resource intensive mobile hybrid/ad hoc data networks supporting high-speed user mobility.

V. CONCLUSION

In this work we have introduced the sectorized ad hoc mobility prediction algorithm for cluster change prediction in mobile ad hoc networks. The sectorized mobility prediction algorithm [7] is successfully extended to hybrid and purely ad hoc networks by introducing the sectorized cluster sector concept for reduction in the area of tracking required and the cluster-sector numbering scheme for the prediction of user movements. Simulation study of the proposed scheme was conducted using OPNET modeler 9.0 with focus on the suitability of the scheme for efficient deployment in next generation networking environments. Simulation test results were observed for prediction accuracy, robustness of the scheme to randomness in user movement and control overhead introduced by the prediction scheme. It is seen that the scheme is capable of high levels of accuracy despite randomness in user movement patterns with minimal amounts of control overhead. It can be seen that the sectorized ad hoc mobility prediction algorithm adapts efficiently to the nuances of the environment. Reduction in control overhead and robustness to the dynamic topology of the network has been observed. Based on the observed results we can conclude that the sectorized method for ad hoc mobility prediction can be successfully deployed in next generation networks based on hybrid and completely ad hoc network topologies.

Comparative study of the prediction scheme with other ad hoc mobility prediction schemes is currently underway.

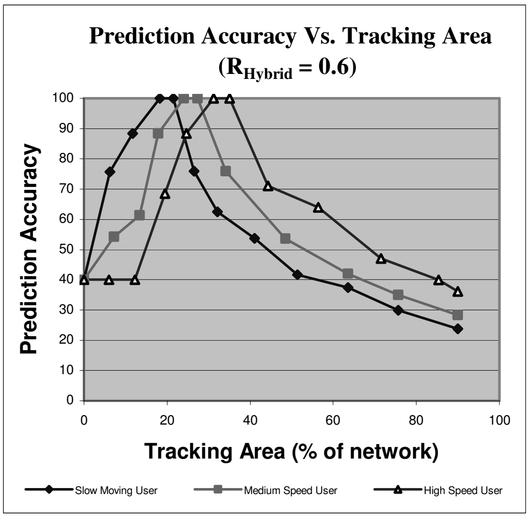

Fig.4. Prediction Accuracy Vs. Tracking Area

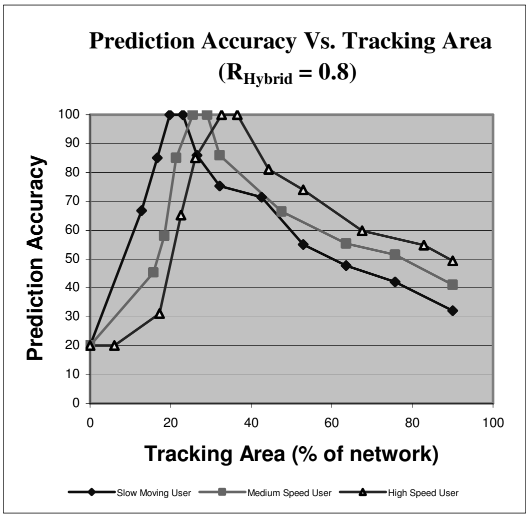

Fig.5. Prediction Accuracy Vs. Tracking Area

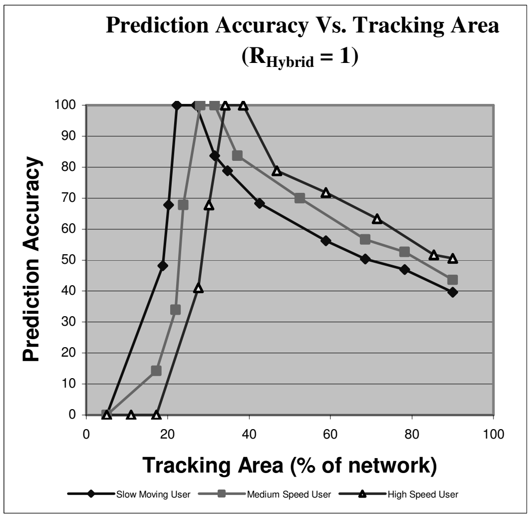

Fig.6. Prediction Accuracy Vs. Tracking Area

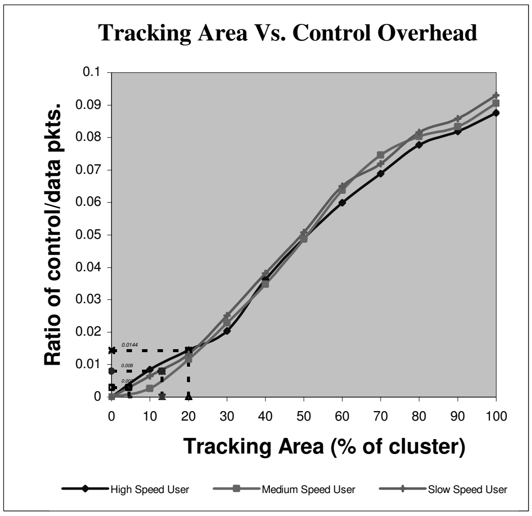

Fig.7 Tracking Area Vs. Control Overhead

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