A Comparative Study of Mobility Prediction in Fixed Wireless Networks and Mobile Ad hoc Networks

Robin Chellappa[+] , Andrew Jennings[++]
School of Electrical and Computer Engineering
RMIT University
Melbourne, Australia.
[+]S2011259@student.rmit.edu.au, [++]ajennings@rmit.edu.au

Nirmala Shenoy
Department of Information Technology
Rochester Institute of Technology
Rochester, NY 14623
ns@it.rit.edu

Abstract— **In this paper we have introduced a mobility prediction scheme that proposes the use of a new sector-based tracking of mobile users, with a sector-numbering scheme to predict user movements. The proposed scheme is applicable for both the fixed network and the ad hoc networking structures. Our study shows that accurate prediction is possible with reduced area of tracking for both types of networks.**

Keywords- mobility prediction; algorithm; wireless network; ad hoc network; resource reservation; handover.

I. INTRODUCTION

Wireless networks can be classified into *Infrastructure Networks* and *Ad hoc networks.* The former type is a network of fixed and wired gateways with bridges called as base stations. A mobile station connects to the network by communicating with its nearest base station that is within its communication radius. The mobility of the node causes it to travel out of range of one base station and to "handoff" to a new base station to ensure connectivity is maintained. In the case of ad hoc networks the infrastructure has no fixed routers. 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 [1]. In order to define a semblance of grouping in ad hoc networks the concept of clustering has been introduced. The purpose of clustering in ad hoc networks is to enhance network manageability and energy economy. The cluster head of each cluster has a bi-directional link with each of its member nodes. As the clusters are dynamic groupings, mobile nodes frequently leave their current cluster of membership and join a neighbouring cluster.

Resource reservation and context transfer to the new connection point should occur prior to handoff or cluster change to enable the user to receive data or services at the new network location at the same level of service. While it is possible to aggressively reserve resources at all locations of the network for a user, this leads to an overall wastage of bandwidth and results in unnecessary blocking of new connections. In order to optimize the efficiency of a resource reservation algorithm an accurate prediction scheme for the future movements of the user is required. The mobility prediction algorithm needs only to identify the next connection point of the mobile user with respect to the network [2]. There is therefore, not a need to predict continually the geographic position of the user.

In this paper we introduce the sectorized mobility prediction algorithm that proposes the use of a new sector-based tracking of mobile users, with a cell-sector numbering scheme to predict the random user movements. The mobility prediction scheme is found to be efficient for both cellular and ad hoc network structures.

Section II gives an overview of related work. Section III introduces the sectorized cell and cluster structures. Section IV discusses the cell-sector and cluster-sector numbering schemes that are employed for random user movements. Mathematical results validating our simulation results in Section VI is given in Section V with the conclusion in Section VII.

II. RELATED WORK

Several mobility prediction algorithms have been proposed for fixed wireless networks. Most algorithms make use of a history base that has a record of the previous movements of users. Taking into account the probability of user 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. Their failure is attributed to an inability to adapt efficiently with the changes in user behaviour.

The Mobile Motion Prediction (MMP) algorithm [3] makes use of the user's movement history. Movements are considered to be a combination of random and regular movements and are matched using a Markov chain model made up of movement circles and movement tracks. However it is assumed in the model that most users have regular movement patterns. The Regular Path Recognition Method [4] attempts to exploit regularity in human behaviour in terms of periodic daily activities such as travelling to work etc., which results in probabilities that can be assigned to used paths. The accuracy of the path detection is dependent on the amount of user profile data in store. It is assumed that all user movements can be contained as a regular path. The Shadow cluster concept [5] 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. Su et al. [6], 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. [7], 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. Sectorized Cell and Cluster Structure

If we assume a hexagonal cell structure as in Fig. 1, there is a region of the cell wherein the probability of handoff is negligible (even zero) – which we define as the No-HO region. The argument is a user in this region of the cell cannot receive beacons of sufficient signal strengths that satisfy the threshold for handoff from any of the neighbouring cells. As a result it would seem reasonable to suggest that a handoff is not possible or desirable. Hence users belonging to this category will not be considered for prior allocation. There is a region in the middle of the cell where the probability of handoff is low – which we define as the Low-HO region. This is because the quality of connection offered to the user in this region of the cell is still sufficient and hence the probability of the user executing a handoff from this region of the cell is fairly low. There is also a region in every cell where the probability of handoff is fairly high - which we define as the High-HO region. This is the region of the cell where the mobile user is able to receive beacons from neighbouring cells that are above the threshold required for handoff. However, it is to be noted that the decision for handoff is not dependent on only the relative signal strength (RSS) measurements. For a successful handoff a goodness function is to be satisfied which would take into account available resources on the contending cells. The RSS value would be weighted into the goodness function value.

Based on the above observations, we suggest a novel method of cell division that makes possible accurate mobility prediction with sufficient reduction in required area of tracking. The cell is divided into three regions with respect to HO probability as No-HO, Low-HO and High-HO regions. It suffices to do this based on RSS values. The width of the regions could possibly be user specific, meaning highly mobile users can have a smaller Low-HO region and a wider High-HO region. The width of the No-HO region would not change, as it is dependant on the BTS and not related to the mobility of the user.

The cell is further divided into sectors and numbered as in Fig. 2. Each sector is adjacent to only one neighbouring cell and it is assumed that it is only to this cell that the user would eventually handoff to. In the ad hoc scenario the cluster structure is quite distinct from the cellular structure.

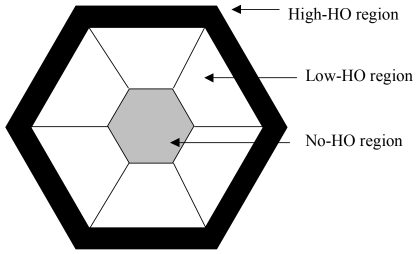

Figure 1. Cell structure based on handover probability

The number of cluster-sectors is dependant on the number of adjacent clusters that are present. The cluster size varies in accordance with the number of nodes entering or leaving the cluster. The sectorization in the ad hoc case is as in Fig. 3.

IV. The Cell-Sector and Cluster-Sector numbering schemes for random user movement prediction

A mobility history base can be used to predict the movements of a user. However, once it has been identified that the user is on a random movement track i.e. on a previously not encountered mobility pattern in the network a method of prediction of the random movements of the user is required. While it is possible to obtain accurate tracking by making the prediction process highly complex the proposed method is computation non-intensive and introduces minimal amounts of additional traffic on the wireless link. We introduce the use of a cell-sector numbering scheme that can predict the next handover point. The proposed numbering scheme is as in Fig. 4. The Cluster-Sector numbering scheme encountered further on is an adaptation of the Cell-Sector scheme and retains all fundamental properties. The scheme can be used with any other cell-numbering scheme and is only for the purpose of mobility prediction.

The cell that the user is resident in (greyed) is always identified as the reference cell 0, i.e., if the user moves from cell 0 in the figure to cell 5 then cell 5 is referred as cell 0 for mobility prediction purposes. Each sector of the resident cell is then identified using $0_i|a_j$ where '0' is the reference cell and 'a' denotes the neighbouring cell to which the user can handoff to from this particular sector of the reference cell. Re-referencing of a neighbour cell is only done if the distance from the original reference cell sector to the present resident sector is at the least 2 cell-sector crossings. The system is robust enough to handle oscillating users between two sectors of different cells without any re-referencing.

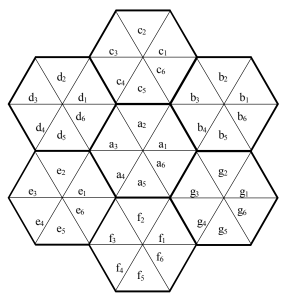

Figure 2. The sectorized cell structure.

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Cell $A \in \{a(i) \mid i = 1,2...6\}$, where each $a(i)$ is a sector

For the ad hoc scenario we introduce the cluster-sector numbering scheme that can be used to predict cluster changes for a mobile user. The proposed numbering scheme is as in Fig. 5. As the number of sectors in a cluster is dynamic we do not reference the cluster-sectors of adjacent clusters as only the identity of the cluster is of interest for prediction purposes. Adapting from the cell-sector scheme each cluster-sector is identified using $0_i|i$ where '0' is the reference cluster and 'i' denotes the cluster that the user is moving towards.

V. Mathematical Results

Let us consider a mobile user who starts a call from within a resident cell and moves executing a "random walk" with movements of various magnitudes. To calculate the probability that the user will become a candidate for tracking i.e., enter the High-HO region of the cell we make use of the jumping rabbit problem [8]. We assume that all movements of the user are along a straight line to simplify the discussion. Let X_n denote the magnitude of the n^{th} movement, n = 1,2…. A positive value of X_n denotes a jump to the right (i.e., towards the High-HO region) and a negative value denotes a jump to the left. If S_0 denotes the initial position then S_n denotes the position of the mobile user after n movements along a random walk.

$$S_n = X_1 + X_2 + \ldots + X_n,\ n = 1,2\ldots \quad (1)$$

We generalize the walk such that the probabilities of the right and left steps are not equal. If p were the probability for the right step then we have the transition probabilities given by,

$$P_{i,i+1} = p = 1 - P_{i,i-1} \text{ where } i = 0, \pm 1, \pm 2 \ldots \quad (2)$$

If the mobile user makes N movements, n_r of them to the right and n_l of them to the left then,

$$N = n_r + n_l \ \ \& \ n_r - n_l = S_N \quad (3)$$

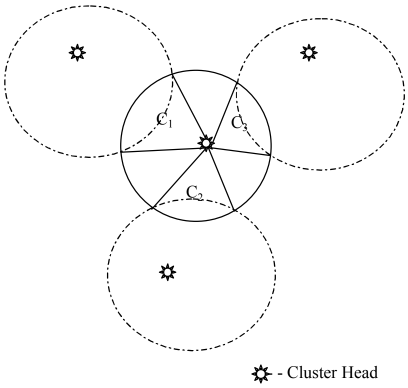

Figure 3. The sectorized cluster structure.

Cluster $C \in \{C_i \mid i = 1,2...n\}$, where,
n is the no.of adjacent clusters.
Each C_i is a cluster - sector.

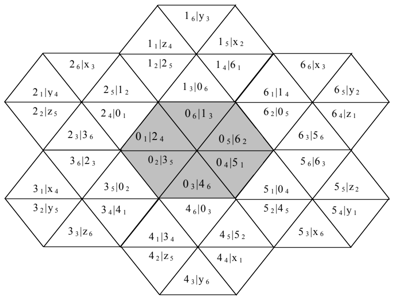

Figure 4. The cell-sector numbering scheme.

> ***Definition :***
> Each sector of cell 0 takes a value $0_i \mid a_j$
> where $i = 1...6;\ a = 1...6;\ j = 1...6$
> further $a = (i+1) \bmod 6\ \&\ j = (i+3) \bmod 6$
> And a neighbouring sector takes a value $a_j \mid 0_i$

Where S_N is the position of the user after N movements, we can write from (3),

$$S_N = 2n_r - N \quad (4)$$

The probability of the user making a sequence of right and left moves and at the end of a total of N moves becoming a candidate for tracking i.e., reach a distance S_{track} is given by the probability of each possible sequence multiplied by the total number of possible sequences.

$$P_N(S_N = S_{track}) \equiv P_N(n_r) \quad (5)$$

[We can reason that $n_r = S_{track} + n_l$]

$$= \frac{N!}{n_r!n_l!} p^{n_r}(1-p)^{n_l} = \frac{N!}{n_r!(N-n_r)!} p^{n_r}(1-p)^{N-n_r}$$

$$= \binom{N}{n_r} p^{n_r}(1-p)^{N-n_r} \quad (6)$$

After the user enters the High-Ho region we assume that the first move of the user inside the High-HO region is in the "away" direction. From the above equations it can be shown that the probability that a user is found at a position "m" after making X moves is given by,

$$P_x(m) = \frac{X!\ p^{1/2(X+m)}(1-p)^{1/2(X-m)}}{[1/2(X+m)]![1/2(X-m)]!} \quad (7)$$

We reason from above that the probability for the first move inside the High-Ho region to be in the "away" direction equals p. Following this the probability that the user is found at the position "m" to handoff after a total of X moves is given by (8).

$$P_x(\text{Handoff}) = p.\frac{(X-1)!\ p^{1/2(X-1+m)}(1-p)^{1/2(X-1-m)}}{[1/2(X-1+m)]![1/2(X-1-m)]!} \quad (8)$$

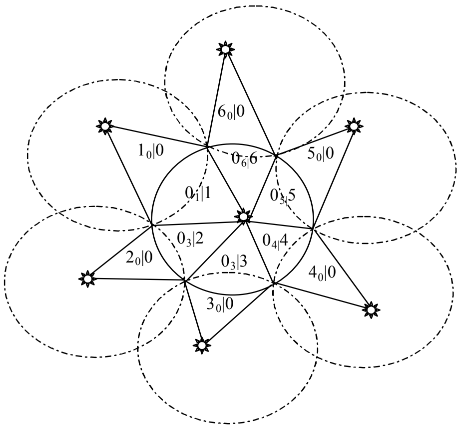

Figure 5. Cluster-Sector numbering scheme

> ***Definition :***
> *Each sectorof cluster 0 takes a value* $0_i \mid i$
> *where* $i = 1,2,...n$
> n *= no.of adjacent clusters of* 0
> *An adjacent sector takes the value* $i_0 \mid 0$

A plot of this function for different values of p (to accommodate the user drift) is shown in the graph in Fig. 6. It can be seen from the plot that there is an optimal tracking region wherein the handoff probability is maximized. This relationship between the High-HO region and the handoff probability supports our simulation results. For the ad hoc case we need to introduce the movement of the cluster head into the probability function. The probability that the mobile user will change its cluster of membership is the probability that the user is found in the tracking region as the cluster size changes. This is calculated by equation (9). The probability that the tracking region starts at a position m_{hh} after X_{cs} cluster size changes can be given as,

$$P_{X_{cs}}(m_{hh}) = \frac{X_{cs}!\, p_{cs}^{1/2(X_{cs}+m_{hh})}(1 - p_{cs})^{1/2(X_{cs}-m_{hh})}}{[1/2(X_{cs}+m_{hh})]!\,[1/2(X_{cs}-m_{hh})]!} \tag{9}$$
$$\text{where, } p_{cs} \text{ is the prob. of cluster size increase.}$$

Probability that a user will change its cluster of membership after X moves in the tracking region is given as in (10).

$$P_x(\text{Cluster change}) = \sum_{m=0}^{S_{Hi-ho}} p.\frac{(X-1)!\; p^{1/2(X-1+m)}(1-p)^{1/2(X-1-m)}}{[1/2(X-1+m)]!\,[1/2(X-1-m)]!} \cdot \frac{X_{cs}!\, p_{cs}^{1/2(X_{cs}+m_{hh})}(1-p_{cs})^{1/2(X_{cs}-m_{hh})}}{[1/2(X_{cs}+m_{hh})]!\,[1/2(X_{cs}-m_{hh})]!} \tag{10}$$
$$\text{such that, } m \sim m_{hh} = S_{Hi-ho}$$
$$\text{where } S_{Hi-ho} \text{ is the size of the tracking region.}$$

A plot of this function for different values of p (to accommodate the user drift) is shown in Fig. 7. It can be seen that maximum probability for the same level of user drift is achieved in the ad hoc case at a much lower value of the tracking area.

VI. Simulation Results

The proposed sectorized mobility prediction algorithm was evaluated in a cellular networking environment making use of OPNET modeler 7.0 as the simulation tool. The algorithm was tested for mobile users of varying speeds. 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 upto 130 km/hr. The movements of the mobile users were 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. It has been found that the proposed scheme is efficient for all types of users and an accuracy of 100% is achievable. However this is dependant on the size of the High-HO region (size of the tracking area). It can be seen from Fig.8 that 100% accuracy is achieved with the required tracking region being 57% for a high-speed user. This augurs well for the scheme when compared to traditional schemes, which require tracking in the complete cell area. The advantages of the scheme are accurate predictions for all types of users and decreased tracking of the user. It can be seen that the higher the speed of the user the larger the tracking area that's required. Also there is inaccuracy introduced in the system as a result of the over-prediction that is observed once the tracking area increases beyond the maximum accuracy level. The inaccuracy with an increased area of tracking is due to predictions prior to the user being on the last leg of its handoff path. We measure accuracy as the ratio between the numbers of successfully predicted handoffs and the number of predicted and missed handovers. The results obtained for the ad hoc scenario are as in Fig.9. The movements of the cluster head and the mobile nodes are an unrestricted random walk. It has been found that the proposed scheme is efficient for all types of users and an accuracy of 100% is achievable. However this is dependant on the size of the tracking area.

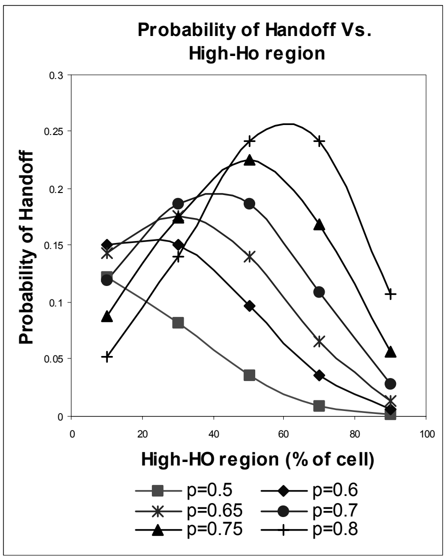

Figure 6. Plot of handoff probability

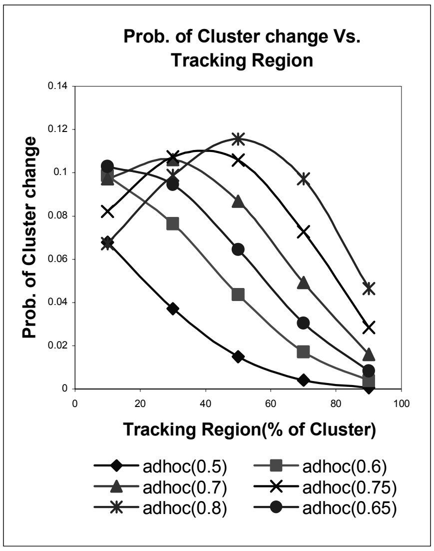

Figure 7. Plot of cluster change probability

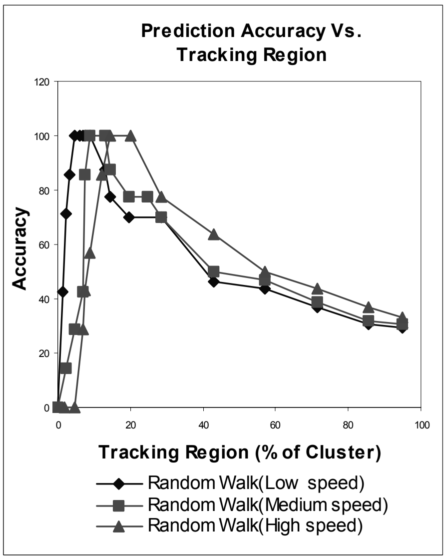

Figure 9. Accuracy Vs. Tracking Area.

Interestingly it has been found that maximum accuracy in the ad hoc case requires a smaller tracking area than the cellular environment. The simulation results obtained are in agreement with the results obtained in our mathematical model in Section IV. Maximum accuracy in the ad hoc case is achieved at a lower value of the tracking area than in the cellular environment for the same levels of user drift.

VII. CONCLUSION

Efficient handling and reservation of resources is vital in mobile wireless networks. In this paper we have presented a mobility prediction algorithm, The Sectorized Mobility Prediction Algorithm that exploits intra-location area movement patterns to accurately predict the inter-location area movements of mobile users.

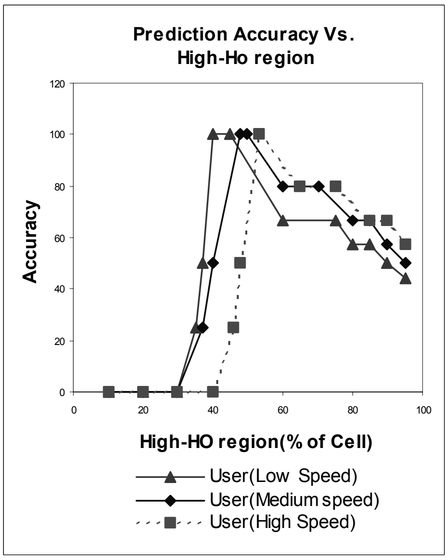

Figure 8. Accuracy Vs. Tracking Area

With an increased knowledge of user movements and with accurate knowledge of user's future movement patterns we ascertain that efficient resource reservation can be achieved. It has been shown to this effect with the help of simulation results for both cellular and ad hoc networks that a high level of accuracy in prediction can be achieved with considerable reduction in the area of tracking. The algorithm does not place any restriction on the movement patterns of user and also does not require detailed knowledge of the geographical surrounds.

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