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The Sectorized Mobility Prediction Algorithm for Wireless Networks

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Abstract

One of the requirements for seamless mobility is efficient resource reservation and context transfer procedures during handoff. If context transfer and resource reservation can occur prior to handoff continuation of the same level of service as at the previous connection point is possible. Resource reservation is required to be non-aggressive for optimal use of limited bandwidth and a low call blocking probability. In this work we present a method of mobility prediction that can aid in achieving seamless mobility. In order to optimize the efficiency of a resource reservation algorithm we believe accurate prediction of the future movements of the user is required.

The aims and contributions of this paper can be summarized as: - (a) Achieve accuracy in prediction with a considerable decrease in the total tracking area of the network and (b) a prediction algorithm that is efficient for both regular and random movements of users.

Keywords: Mobility prediction, seamless mobility, resource reservation, handover, wireless networks.

1. Introduction

With the advent of resource intensive mobile applications there is a need for seamless mobility. Seamless mobility requires continuous resource reservation and efficient context transfer as the user moves from one location in the network to another. Resource reservation and context transfer to the new connection point should occur prior to handover to enable the user to receive the data or services at the new location, at the same level of service as at the previous location. 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 calls. In order to optimise the efficiency of a resource reservation algorithm an accurate prediction of the future movements of the user is required. Hence there is a need for highly accurate mobility prediction techniques.

The mobility prediction algorithm needs only to identify the next connection point of the mobile user with respect to the network [1]. There is therefore, not a need to predict continually the geographical position of the user. While techniques such as the Global Positioning System (GPS) are able to track the movements of user continually they require additional receivers. The mobility prediction algorithm introduced in this work proposes a new sector-based tracking method for mobile users to predict their regular movements, with a cell-sector numbering scheme to predict their random movements. Additional receivers are not required.

In this paper we have introduced the sectorized mobility prediction algorithm which, (a) can be employed to minimise the number of base stations/access points required for resource reservation, (b) achieves accuracy in prediction without introducing additional complexity in the prediction algorithm or in the network structure, (c) is efficient for both the regular and the random movements of the user and, (d) has the potential to be extended to an ad hoc networking environment and performs efficiently for all types of users i.e., low-speed, medium-speed, high-speed and aircraft or military users. Our simulation results prove that accuracy in prediction can be achieved with a considerable decrease in the total tracking area of the network.

Section 2 gives an overview of related work. Section 3 introduces the sectorized cell structure and the sectorized mobility history base (SMHB). Section 4 discusses the sector-cell numbering scheme that is used for random movements of users. Mathematical analysis in support of the simulations results presented in Section 5 is explained in Section 6 with the conclusions in Section 7.

2. Related work

Several mobility prediction algorithms have been proposed. Most of the algorithms make use of a history base that has a record of the previous movements of users. 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 [2]. 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 algorithm is dependent on the available history of the user's movement pattern. As a result the performance of the MMP algorithm is accurate with regular movement patterns but decreases linearly as random movement increases.

The Hierarchical Position Prediction (HPP) Algorithm [4] makes use of the user's history of movements in addition to the instantaneous RSSI measurements of surrounding cells. While agreeing that the next cell mobility of the mobile user is governed directly by the movement pattern of the user within the current cell we argue that the tracking of the user need not be performed in the complete cell area. The HPP algorithm remains reasonably accurate (75%) despite the influence of random movements.

The Profile based Next-Cell Prediction algorithm [5] predicts based on a location classification and a user movement history. Prediction is found to be 80% accurate for regular movements and 70% accurate for random movements. However movements are restricted to indoor locations such as an office, corridor or common room.

The Shadow cluster concept [6] 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.

The user movement tendency prediction algorithm [7] characterizes each user by making a judgement whether the user is moving or not. The required inputs are user's location and velocity estimation records, local geographical features and statistical traffic information. The algorithm also works on the assumption that the traffic speed distribution is constant for each road and that the speed of the user is a constant for each road. The required detail in input to the information processing system and the assumptions make deployment of the algorithm difficult. Also prediction is in terms of the possible physical locations of the mobile user and not in terms of the possible connection points on the network.

The Regular Path Recognition Method [8] 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. Making use of recorded cell patterns the most likely path of the user is detected. In a way this prediction method seems to be an extension of the mobility prediction model making use of the segment criterion and suffers from those same drawbacks. The accuracy of the path detection is dependent on the amount of user profile data in store. Also it is assumed that all user movements can be contained as a regular path.

The Neural-Network Based Prediction Algorithm [9] proposes a hierarchical scheme that takes into account both global and user level information while performing the prediction. The type of method proposed however requires the design of a neural network as well as prior detailed geographical knowledge of the cellular structure. However the analysis of this method stresses that the next cell can be predicted accurately based on movement paths within the cell and prediction is user independent.

3. Sectorized cell structure and the sectorized mobility history base (SMHB)

If we assume a hexagonal cell structure as shown 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 that 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 and/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 shown in Fig.2. Each sector is adjacent to only one neighbouring cell and for all practical purposes it is assumed that it is only to this cell that the user would eventually handoff to. The algorithm does follow traditional algorithms in that we make use of previously recorded mobility patterns of the user. We follow the principle that the mobility of a user is a combination of regular and random movement patterns. Traditional algorithms store the past movements of the user from one cell to another in a mobility history base (MHB) as shown in Fig.3, and depending on the current cell of the user, predict the most likely subsequent cell.

The drawback of these algorithms is that the accuracy is directly related to the length of the mobility track i.e., if the user is in the middle of a recorded mobility track after having followed it accurately for its x previous movements then the probability of it continuing with the same path for its $(x+1)^{th}$ movement is sufficiently high than if otherwise. We propose the use of the sector mobility history base (SMHB) as shown in Fig.4, which stores the positions of the user on a sector-by-sector basis instead of a cell-by-cell basis. As we track the movements of the user we can identify HO points as the user moves from one cell to another cell. This might result in an almost six-fold increase in the length of the stored pattern but the increased accuracy of prediction is bound to compensate for this overhead. This six-fold increase however is the worst-case scenario, where the user insists on moving in a circular pattern within each of its cells of residence, which is a rare movement pattern. The advantage of the sector-by-sector tracking method is that it would be efficient even in cases where the mobile user has not sufficiently progressed along a previously recorded mobility track. If we record the past movements cell by cell then the no. of possible handover points from each cell assuming a hexagonal cell structure is 6.

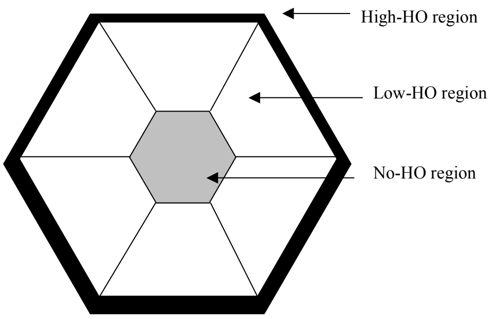

Figure 1. Cell structure based on handover probability

In the case of sector-by-sector recording the no. of possible handover points can be brought down to 1 (the cell with which the current sector shares an edge with) or at the very least to 3 (the cell with the common edge and the 2 cells that share vertices with the current sector), which still is a two-fold decrease in the sample space. This decrease in the no. of possible handover points contained in the sample space results in an increase in the probability of an accurate prediction. To increase the accuracy of prediction for users who haven't sufficiently progressed along a recorded mobility path we treat them as users in a random walk mode as explained in Section 4.

4. The cell-sector numbering scheme for random user movement prediction.

While the regular movements of the user are predicted using a SMHB 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. 5.

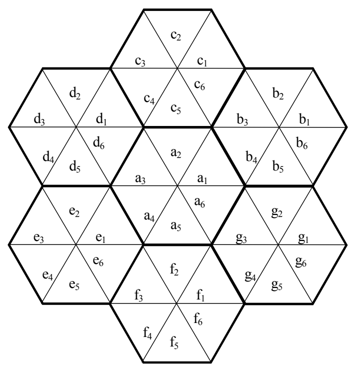

Figure 2. The sectorized cell structure

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

Each $a(i)$ is a sector.

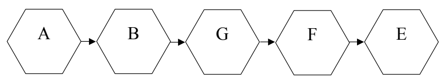

Figure 3. Mobility history base

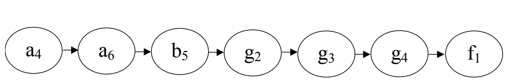

Figure 4. Sectorized mobility history base

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. The scheme sits on top of any other cell-numbering scheme and is only for the purpose of mobility prediction. As shown in the Fig.5, 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.

> ***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 $a_j \mid 0_i$

The handover algorithm employing both methods for mobility prediction can be defined as follows:

PositionUpdate (user);
Employ SMHB for regular movements
IF *user_direction towards* $posn_{next}$*(user);*
  predicted_cell = $posn_{next}$*(user);*
END IF;
ELSE *Employ random prediction*
 IF user_region == H − ho region
  AND *user_direction == away*
  IF *current_sector* $== 0_j \mid a_i$
   predicted_sector $= a_j \mid 0_i$;
   predicted_cell = a;
   prepare Handoff to cell(a);
  END IF;
 END IF;
END ELSE;

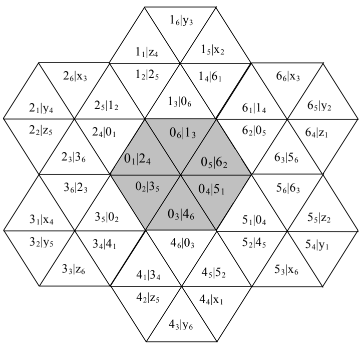

Figure 5. The cell-sector numbering scheme

5. 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 movement of the mobile users 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. 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.6 that the 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. We measure accuracy as the ratio between the numbers of successfully predicted handoffs and the number of predicted and missed handovers

$$Accuracy = \frac{\text{No.of Handoffs}}{\text{No.of Predictions} + \text{Misses}}$$

6. 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 [10]. 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.

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

Taking the interval (t,∞) to represent the High-HO region, where t is a fixed positive the user moves untracked for $S_n \le t$ and as soon as $S_n > t$ tracking traffic is introduced in the network.

If the number of movements to reach the High-Ho region is N then,

$$P(N = n) = p_r(S_1 \le t, \ldots S_{n-1} \le t, S_n > t) \quad (2)$$

is the probability to be computed.
Assuming $A_n = (S_n > t)$, then its complement is written as $A_n^C = (S_n \le t)$.

We can therefore write,

$$p_r(N = n) = p_r(A_1^C \ldots A_{n-1}^C A_n) \quad (3)$$

Also,

$$p_r\left(\bigcup_{i=1}^{n} A_i\right) = \sum_{i=1}^{n} p_r(A_1^C \ldots A_{i-1}^C A_i)$$

$$= p_r(N \le n)$$

or,

$$p_r(N>n) = p_r\left(\bigcap_{i=1}^{n} A_i^C\right)$$

$$= p_r(S_1 \le t, \ldots S_n \le t) \equiv G_n(t) \quad (4)$$

$G_n(t)$ represents the probability that the user did not overshoot the position t after the first n jumps which is the requirement for the user to become a candidate for tracking.

$$\Rightarrow p_r(N = n) = G_{n-1}(t) - G_n(t), \text{ for } n = 1,2\ldots$$

with $G_0(t) = 1$.

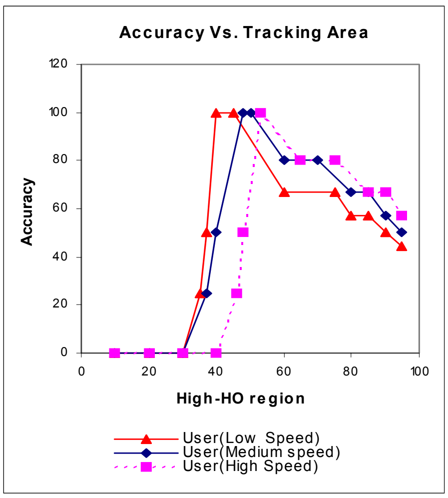

Figure 6. Accuracy vs. Tracking Area

The average number of movements that the user needs to make to become a candidate for tracking is given by,

$$E(N) = \sum_{n=1}^{\infty} n\, p_r(N = n)$$

$$= \sum_{n=0}^{\infty} G_n(t)$$

$$= 1 + \sum_{n=1}^{\infty} G_n(t) \quad (5)$$

The calculation of this value however requires knowledge of all $G_n(t)$. 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,

$$P_{i,i+1} = p = 1 - P_{i,i-1} \text{ where } i = 0, \pm 1, \pm 2 \ldots \quad (6)$$

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

$$N = n_r + n_l \quad (7a)$$

Also,

$$n_r - n_l = S_N \quad (7b)$$

where S_N is the position of the user after N movements.

We can write from the above two equations,

$$S_N = 2n_r - N. \quad (8)$$

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.

$$P_N(S_N = S_{track}) = P_N(n_r) \quad (9)$$

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

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

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

$$= \binom{N}{n_r} p^{n_r} (1-p)^{N-n_r} \quad (10)$$

For a symmetric random walk we have $p = \frac{1}{2}$ which reduces the equation to,

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$$= \binom{N}{n_r}\frac{1}{2^N} \tag{11}$$

Applying the De Moivre-Laplace theorem we have, for large N,

$$P(n_r) \approx \frac{1}{\sqrt{2\pi Np(1-p)}}e^{-(n_r-Np)^2/2Np(1-p)} \tag{12}$$

Substituting for p and $n_r = \dfrac{S_N + N}{2}$ we have,

$$P(S_N = S_{track}) \approx \frac{1}{\sqrt{N\pi/2}}e^{-S_{track}^2/2N} \tag{13}$$

provided S_{track} is of the order of $\sqrt{N}$.

Also we can conclude that [11],

$$P(S_N \le S_{track}) \approx \frac{1}{2} + erf\frac{S_{track}}{\sqrt{N}} \tag{14}$$

From the above two equations we can deduce that the probability that the mobile user while following a random walk will not become a candidate for tracking is given by,

$$P(S_N \langle S_{track})$$

$$\approx P(S_N \le S_{track}) - P(S_N = S_{track})$$

$$\approx \frac{1}{2} + erf\frac{S_{track}}{\sqrt{N}} - \frac{1}{\sqrt{N\pi/2}}e^{-S_{track}^2/2N} \tag{15}$$

After the user enters the High-Ho region the probability that this user will handoff after say X moves can be calculated. 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,

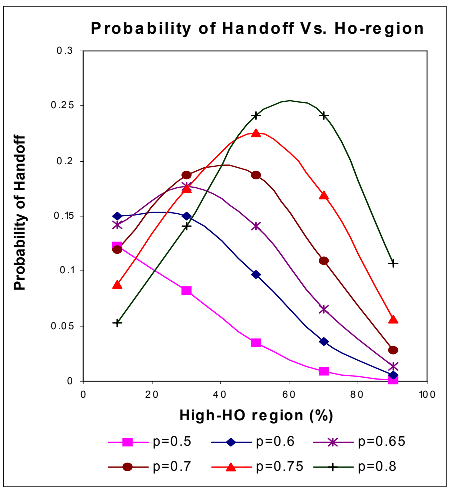

Figure 7. Plot of handoff probability

$$P_x(m) = \frac{X!\, p^{1/2(X+m)}(1-p)^{1/2(X-m)}}{[1/2(X+m)]![1/2(X-m)]!} \tag{16}$$

Reasoning from the above equation we obtain the probability that the first move inside the High-Ho region is in the "away" region 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 as,

$$P_x(\text{Handoff}) = p.\frac{(X-1)!\, p^{1/2(X-1+m)}(1-p)^{1/2(X-1-m)}}{[1/2(X-1+m)]![1/2(X-1-m)]!} \tag{17}$$

A plot of this function for different values of p (to accommodate the user drift) is shown in the graph in Fig. 7. It can be seen from the plot that the handoff probability of the user varies with respect to the width of the High-Ho region. 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. It has been assumed that the user makes 10 jumps in the High-HO region.

7. Conclusion

Efficient handling and reservation of resources is vital in mobile wireless networks. With the advent of real-time data networks and the increasing need for seamless mobility, efficient resource reservation techniques and fast handover algorithms are a necessity. In this paper we have presented a mobility prediction algorithm, The Sectorized Mobility Prediction Algorithm that exploits intra-cell movement patterns to accurately predict the inter-cell movements of mobile users. 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 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.

Mobility Prediction techniques while finding applications in commercial networks for efficient resource reservation and fast handoff mechanisms, are also of considerable use in military mobile ad-hoc networks. Wireless networks allow a more flexible communication model than traditional wired networks since the user is not limited to a fixed physical location. Unlike cellular wireless networks mobile ad-hoc networks do not have any fixed wired communication infrastructure.

We plan to extend the sectorized mobility prediction algorithm to the ad-hoc networking domain to assist in context and routing information transfer. By exploiting a mobile user's non-random travelling pattern we can predict the future states of the network topology changes and provide transparent access during the period of change [12].

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