An Intelligent Handover Scheme for the Next Generation Personal Communication Systems

Ming-Hui Jin, Eric Hsiao-Kuang Wu, and Chao-Hsu Chang

Abstract: **Driven by the growing number of the mobile subscribers, efficient channel resource management plays a key role for provisioning multimedia service in the next generation personal communication systems. To reuse limited channel resources, diminishing the coverage areas of cells seems to be the ultimate solution. Thus, however, causes more handover events. To provide seamless connection environment for mobile terminals and applications, this article presents a novel handover scheme called the intelligent channel reservation (ICR) scheme, which exploits the location prediction technologies to accurately reserve channel resources for handover connections. Considering the fact that each mobile terminal has its individual mobility characteristic, the ICR scheme utilizes a channel reserving notification procedure (CRNP) to collect adequate parameters for predicting the future location of individual mobile terminals. These parameters will be utilized by the handover prediction function to estimate the expected handover blocking rate and the expected number of idle channels. Based on the handover prediction estimations, a cost function for calculating the damages from blocking the handover connections and idling channel resources, and a corresponding algorithm for minimizing the cost function are proposed. In addition, a guard channel decision maker (GCDM) determines the appropriate number of guard channels. The experimental results show that the ICR scheme does reduce the handover-blocking rate while keeping the number of idle channels small.**

Index Terms: **Handoff, mobile, next generation personal communication system.**

I. INTRODUCTION

Seamless mobile high-quality service provision for on-going connections is one of the critical issues for the next generation personal communication networks [1]. Distinct from the traditional 2G cellular system (such as GSM), the new generation personal communication systems (such as 3G network and the 4G systems) offer not only the real time (such as voice) services, but also the bursty traffic (such as data) services. This greatly encourages and enhances the existing applications to shift their platform to the mobile computing environments. To provide higher bit rates towards mobile multimedia applications in the growing worldwide markets, continuous and sufficient channel resources must satisfy mobile subscribers quality of services (QoS) requirements in the next generation personal communication systems.

In recent years, there has been great interest in developing efficient mobility management schemes to handle node mobility within a mobile multimedia system and accommodating a maximum number of mobile applications under the limited channel resources has become an urgent challenge. To satisfy the eagerness of profuse bandwidths under limited resources, diminishing the geographical coverage areas of cells to have the less competing clients for each base station while increasing the channel reusability seems to be the most adopted solution. This, however, increases the number of handover events. A handover connection may be blocked if there is no available channel resource in the new cell[1]. Since the blocking of a handover request is generally believed to be less desirable than the blocking of a new connection [2]–[11], specific schemes are required to prioritize the handover connections. Besides the soft handover[2] [11], the existing channel assignment schemes could be generally classified into two categories as follows [7]–[9].

1. Queuing priority schemes (QPS): In this type of schemes, each base station provides a waiting queue for the mobile terminals with on-going connections, which enter a handover area from one of its adjacent cells. As there are available channels, a free channel will be assigned to a mobile terminal that is currently in the waiting queue. As the queue is empty, the channel could be assigned to any mobile terminal which attempts to initiate a new connection [8].
2. Reserved channel schemes (RCS): In this type of schemes, the channels of each cell are divided into two distinct sets. The first set of channels are called normal channels which serve both handover and new connections, and the second set of channels are called guard channels which are reserved for serving handover connections only [7].

Novel applications such as real-time transactions desire seamless mobile computing environment [12], [13]. For these real-time transactions, the timing constraints [14] make the QPS inappropriate since they are required to wait for free channels once all of the available channels have been allocated. Thus, to assure the seamless services in the next generation personal communication systems, reserving channels to assure the service quality for handover activities is necessary for the real-time applications and hence this article considers an intelligent scheme to reserve the channel efficiently.

Manuscript received February 20, 2003; approved for publication by Luciano Lenzini, Division II Editor, March 3, 2004.

M.-H. Jin is with the Department of Computer Science and Information Engineering, National Taiwan University, Taipei, Taiwan, email: jinmh@db.csie.ncu.edu.tw.

E. H.-K. Wu and C.-H. Chang are with the Department of Computer Science and Information Engineering, National Central University, Chung-Li, Taiwan, email: hsiao@csie.ncu.edu.tw, cschang@wmlab.csie.ncu.edu.tw.

---

[1] In 3G WCDMA system, dealy-sensitive connections with minimal bandwidth requirements may be blocked as there are no sufficient available radio resources. In this paper, we focus on reserving bandwidth resources for handover real-time connections and a channel is defined to be the required minimal bandwidth in the cellular packet switch network.

[2] The soft handover scheme allows each mobile terminal to connect all the base stations it involves. In power-controlled CMDA systems, the soft handover is useful because it significantly reduces the notorious near-far problem. However, it requires additional resources. Thus, in this paper, we ignore the soft handover scheme.

Reserving guard channels for handover clients urges prudent consideration. Insufficient reservation impels handover connections to compete the free channels with new connections and brings a higher handover blocking rate. On the other hand, prodigal reservation might increase the number of the idle channels. A channel is classified as an idle channel if it is reserved but has not been assigned to any connections. It is well accepted that the new-connection blocking rate increases with the number of the idle channels. Thus, determining an appropriate number of guard channels for handover connections is an essential issue for handover management.

The connectivity and mobility characteristics of the mobile terminals around a particular cell determine the number of handover events of the corresponding BS (base station). Specifically, the number of guard channels reserved in each BS should be varied based on the connectivity and mobility of the active mobile terminals nearby. Therefore, a distributed call admission control scheme [15], [16] has been proposed to calculate the proper number of guard channels of each BS according to the traffic loads of the adjacent cells. The total required bandwidth for both handover and existing connections is estimated under the assumptions of exponentially-distributed channel holding time and perfect knowledge of the rate of handover connections. These assumptions are unrealistic in real cellular networks.

In addition to traffic load considerations, user mobility prediction provides an effective approach for guard channel determination [2]–[6]. If the future time-location information of mobile terminals is predictable, it is expected that the base stations could reserve corresponding channels for handover connections accurately. The symmetric random walk model has been widely adopted among researchers in characterizing individual movement behavior [10], [15]. In such a model, a mobile terminal will move to any one of the neighboring cells with an equal probability after leaving a cell. This assumption does not take into account the geographical nature such as streets and highways and hence may provide inaccurate mobility prediction information.

To improve the accuracy of the future time-location information prediction of mobile terminals, the tangent velocity of each mobile terminal provides an entry point [2]–[6], [17]–[21]. Several previous researches about handover reservation employ the tangent velocity approach to estimate the expected number of new coming handover connections [2]–[6]. In [2], the authors predict the future time-location information of each mobile terminal according to its tangent velocity directly. The approaches in [3]–[6] estimate the time-varying location probability[3] of each mobile terminal according to a sequence of their previous positions and then calculate the final value.

Although predicting the future time-location information by employing the tangent velocity approach is concrete, however, this approach brings several disadvantages. First, it requires mobile terminals to spend a great amount of precious electronic power to sense and then measure a sequence of positions through the help of GPS or other locating mechanism [20], [21]. Second, the prediction is effective only within a short range of time. The ability of location predictions is restricted and hence the time-varying location probability of each mobile terminal varies often.

In addition to the tangent velocity approach, the profile based strategy [22], [23] which employs the regular moving behavior of mobile terminals reveals another possibility for location prediction. In the profile based strategy [22], [23], the author assumed that the time-varying location probability of each mobile terminal was given and would be maintained in their profiles, and the author suggested that the time-varying location probability could be derived from the long-term moving history. In [24], we realized the goal of deriving the time-varying location probability from each mobile terminal's moving history by utilizing a data model called moving behavior and a set of data mining algorithms. In this article, location prediction based on the moving behavior of each mobile terminal is classified as the behavior based approach. Compared with the tangent velocity approaches, the advantages of behavior based approach could be summarized below. 1) The prediction results could last for a longer time. 2) The proposed approach is cost effective since it requires mobiles to pay no power consumption for estimating their current positions and does not require them to continue communicating to the system through expensive wireless channels. 3) This approach could also work for mobile terminals which are in idle mode; however, the tangent velocity approach is only effective in the situation that the mobile terminals are in the ready mode. On the contrary, the predictions of the behavior based approach are inaccurate for mobile terminals with irregular moving behavior.

Each mobile terminal has its individual mobility characteristic and regularity. Some mobile terminals move regularly and others do not. Thus, designing a scheme which applies an appropriate location prediction strategy to estimate the time-varying location probability of each active mobile terminal according to its mobility characteristic is critical. To achieve this goal, we propose a channel reserving notification procedure (CRNP) in Section III to intelligently apply an appropriate location prediction approach to each active mobile terminal according to their current mobility characteristic.

The time-varying location probability [17], [24] could be used to estimate the handover prediction of each mobile terminal to each base station. For active mobile terminal X, base station B, and time interval $(t_i,\ t_j)$, the handover prediction of X to B specifies the probability that mobile terminal X will arrive to base station B in the time interval $(t_i,\ t_j)$. With the knowledge of the handover prediction functions, for each time interval $(t_i,\ t_j)$, each base station could calculate the expected handover blocking rate and the number of idle channels as the number of its guard channels in this time period is determined. This explains that the handover prediction functions are helpful in determining guard channels because the goal of guard channel decision maker (GCDM) which determines the number of guard channels is to minimize the handover blocking rate and the number of idle channels simultaneously.

However, reducing the number of idle channels will increase the expected handover blocking rate, and vice versa. Thus, minimizing the expected number of idle channels and the expected handover blocking rate simultaneously is extremely difficult.

---

[3] For each time interval $(t_i,\ t_j)$ and a region Q, the time-varying location probability of a mobile terminal specifies the probability that the mobile terminal will stay in the region Q in the time interval $(t_i,\ t_j)$.

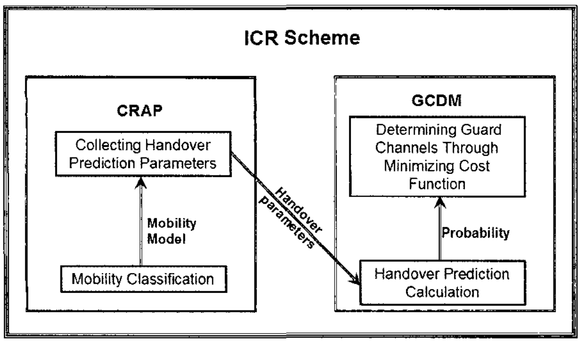


Fig. 1. The flow chart and the functions of the ICR scheme.

This motivates us to design a cost function which considers the expected number of idle channels and the expected handover blocking rate into a cost value and then introduce an algorithm to minimize the cost function for the GCDM.

In this article, we continue our study in [24] to apply the moving behavior for handover management. A novel channel reservation scheme called the intelligent channel reservation (ICR) scheme, which consists of the CRNP and the GCDM, is proposed. Fig. 1 shows the flow chart for the cooperation and the main functions of the CRNP and the GCDM. The CRNP is in charge of collecting the parameters for the handover predictions and preparing them for the GCDM in the corresponding cells. Since the CRNP takes two location prediction approaches into account, the mobility model of each active mobile terminal is intelligently specified first according to their moving regularity. Whenever the GCDM receives a set of handover prediction parameters from the CRNP in other cells, it calculates the handover predictions and then applies them to determine an appropriate number of guard channels through minimizing the cost function proposed in Section III.

This paper is organized as follows. In Section II, the time-varying location probability functions for the tangent velocity approach and the behavior based approach are introduced and then the calculations of the handover prediction functions and their parameters are introduced. In Section III, the ICR scheme which consists of the CRNP and the GCDM is depicted to determine the guard channels for the active mobile terminals. Experiments and comparisons are described in Section IV and the conclusion is drawn in Section V.

II. MOBILITY MODELS AND HANDOVER PREDICTIONS

In the ICR scheme, the GCDM determines the number of guard channels of a cell according to the handover prediction function, whose parameters are determined by the CRNP. In this section, two mobility models employed are briefly introduced in Section II-A and then their corresponding handover prediction functions for the GCDM are proposed in Section II-B. The formulas for deriving the handover prediction parameters are proposed in Section II-C. The handover prediction functions of a mobile terminal is chosen based on the moving regularity and hence an algorithm called the moving regularity classification (MRC) algorithm is proposed in Section II-D to determine the moving regularity of mobile terminals.

A. Mobility Models

A.1 Mobility Model for Regular Mobile Terminals

If a mobile terminal possesses regular moving behavior, then it often moves on the same set of paths and the arrival times to individual location points of the paths are similar. Based on this point of view, the moving behavior of a mobile terminal should contain not only the vertices of the moving paths where the mobile terminal often passes through, but also the information about the time at which the mobile terminal visits each vertex.

Fig. 2 shows an example of a mobile terminal's moving behavior. In this example, the moving period of the mobile terminal is a day. In most days, the mobile terminal follows one of the two paths to move from l_1 at about 7:00AM to l_8 at about 8:30AM, stays there until about 12:00PM and then goes to an unpredictable location (break time for lunch with random walk mobility model). At about 13:30, it returns to l_8 and stays there until about 17:30. At that time, it chooses one of the original two paths to go back to l_1 at about 19:30PM. In real cases, the arrival time to each position is not always the same. Specifically, the arrival time to each location could be represented by a random variable.

Based on the concept above, in [24], we defined the moving behavior of each mobile terminal to be a partial ordered set $\langle V, E, C_E\rangle$ to describe their mobility model as follows, and provided a set of data mining procedures to derive the moving behavior from their long-term moving history.

- $V \subseteq \{(C,t,s) \in L \times T \times N\}$ is the set of all moving states in which L is the set of all cells, T is the set of all normal distributed random variables and N is the set of all natural numbers. We denote, for each moving state $v_i = (C_i, t_i, s_i) \in V$, C_i is the cell ID of v_i, t_i is the time at which the corresponding mobile terminal arrives in C_i, μ_i, and σ_i are the mean and standard deviation of t_i, and s_i or $S(v_i)$ is the support of v_i.
- E is a subset of $V \times V$.
- For each $e = (v_i, v_j) \in E$, $C_E(e)$ is defined to be the confidence that the mobile terminal will change its moving state to v_j given the mobile terminal is in the moving state v_i.

A.2 Mobility Model for Irregular Mobile Terminals

For mobile terminals with irregular moving behavior, applying their moving behaviors to predict their future time-location information will cause inaccurate prediction results. Therefore, whenever the moving behavior of a mobile terminal is determined to be irregular, the system will apply the tangent velocity approach to predict its future time-location information.

Fig. 3(a) shows the simplest procedure of calculating the tangent velocities of mobile terminals. In this procedure, the system calculates the tangent velocity of each mobile terminal from its current and previous time-location events. A time-location event of a mobile terminal is an ordered pair $(t,p)^4$ which de-

---

[4] In this article, we focus on two-dimensional space and hence a time-location event of a mobile terminal is a triple (t,x,y).

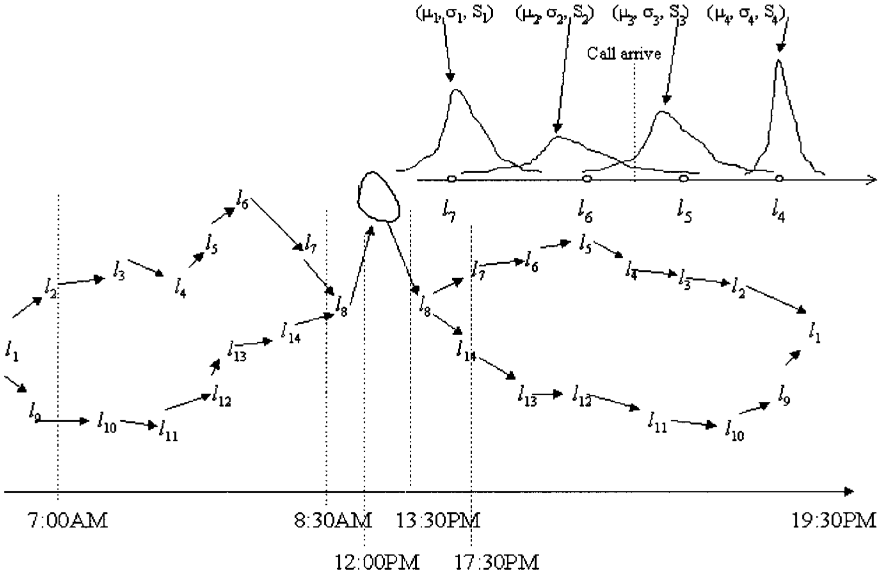


Fig. 2. A moving behavior example.

scribes the event that the mobile terminal stays at position p at time t. Although this procedure is simple and concrete, however, it might not be reliable enough. Figs. 3(b) and 3(c) show the examples that the tangent velocity of a mobile terminal becomes faster and slower temporarily, and Fig. 3(d) shows an example that the mobile terminal moves toward different direction temporarily. The main factor which causes the calculation unreliable is that the sample size for derivation is insufficient. If the prediction procedure could also consider other time-location events, then the noises may be removed. This suggests us to adopt a statistical procedure which predicts the future time-location information of each mobile terminal based on a sequence of their previous time-location events.

In [17], the authors first assume that the mobile terminals follow the two-dimensional Brownian motion with drift mobility model and then apply a statistical procedure to derive the time-varying location probability of each mobile terminal in (1) from a sequence of their time-location events. Assume that the v_x, v_y, D_x, and D_y are the means and the diffusions of the tangent velocity in the x and y directions, then the probability density function $P_X(x, y, t|x_0, y_0, t_0)$ which expresses the probability that mobile terminal X will stay at position (x, y) at time t given X stays at position (x_0, y_0) at time t_0 is

$$P_X(x, y, t|x_0, y_0, t_0) = \frac{1}{2\pi\sqrt{D_x D_y}(t - t_0)} \times \exp\left(\frac{-(x - x_0 - v_x(t - t_0))^2}{2D_x(t - t_0)} - \frac{(y - y_0 - v_y(t - t_0))^2}{2D_y(t - t_0)}\right). \tag{1}$$

B. Handover Prediction

B.1 Handover Prediction for Irregular Mobile Terminals

In this section, we formally define the handover prediction $HP(X, C_j, t_0, t)$ to be the probability that X will arrive the cell C_j in the time interval (t_0, t) given X is not in C_j at time t_0. If the system assumes that a mobile terminal X moves irregularly at about time t_0, then it will apply (1) to predict the future time-location information of X. Thus, it is clear that (2) is the handover prediction of X, where Q_j is the coverage area of cell C_i.

$$HP(X, C_j, t_0, t) = \begin{cases} 0, & \text{if } t < t_0 \\ \int_{t_0}^{t} \iint_{(x,y)\in Q_j} P_X(x, y, z|x_0, y_0, z_0)\,dx\,dy\,dz, & \text{if } t \geq t_0 \,. \end{cases} \tag{2}$$

B.2 Handover Prediction for Regular Mobile Terminals

Fig. 4 shows the probability density function (p.d.f.) of the time at which mobile terminal X arrives in cell C_j. According to the definition of moving behavior, if it is given that X will arrive in cell C_j, then the probability that X arrives in cell C_j in the time interval (t_0, t) is the area of the region colored in gray. According to the Theorem 1 in the appendix, we conclude

$$HP(X, C_j, t_0, t) = \begin{cases} 0, & \text{if } t \leq t_0 \\ \dfrac{\Phi\left(\dfrac{t - \mu_{X,j}}{\sigma_{X,j}}\right) - \Phi\left(\dfrac{t_0 - \mu_{X,j}}{\sigma_{X,j}}\right)}{1 - \Phi\left(\dfrac{t_0 - \mu_{X,j}}{\sigma_{X,j}}\right)} \times P_{X,j}, & \text{otherwise,} \end{cases} \tag{3}$$

where

$P_{X,j}$ denotes the probability[5] that X will pass through cell C_j.

---

[5] The probability could be derived from the function $C_E(\cdot)$ maintained in the moving behavior of X.

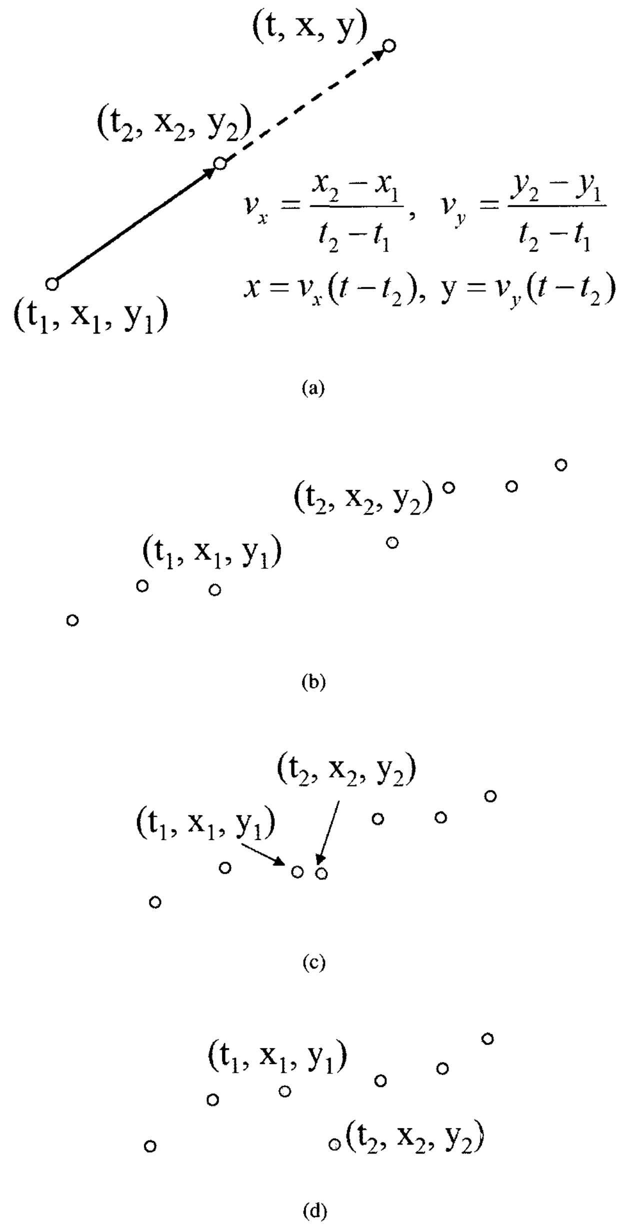


Fig. 3. (a) The simplest procedure of the tangent velocity calculation, (b) tangent velocity becomes faster temporarily, (c) tangent velocity becomes slower temporarily, (d) moves toward different direction temporarily.

- $\mu_{X,j}$ and $\sigma_{X,j}$ are the mean and standard deviation of the arrival time that mobile terminal X will arrive in C_j.
- $\Phi(\cdot)$ denotes the cumulative distribution function (c.d.f.) of the standard normal random variable.

B.3 Comparison of Handover Prediction (2) and (3)

According to [17], the handover prediction (2) requires the mobile terminals to estimate a sequence of their position and then calculate the parameter D_x, D_y, v_x, and v_y from the sequence of time-location information [17]. After the density function is derived, a complex calculation must be executed for calculating the handover prediction (2). Thus, the cost for finding handover prediction (2) is much expensive than finding the handover prediction (3)^6. Therefore, if the system assumes that mobile terminal X moves regularly, then the system would like to employ the handover prediction based on the moving behavior of X to reduce both the calculation and measuring costs.

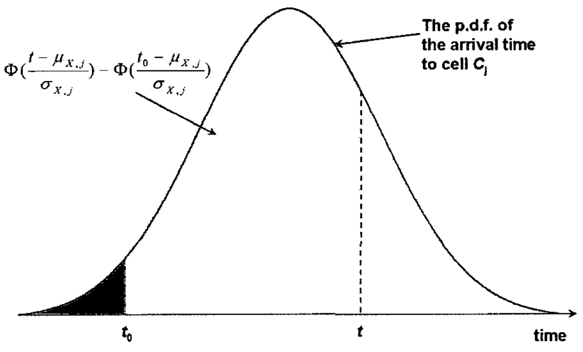


Fig. 4. The handover prediction calculation.

C. Parameters Determination for Handover Prediction

At each base station, the ICR scheme provides the GCDM to determine the number of guard channels according to the handover prediction of all the active mobile terminals near by. Because the parameters for handover predictions are required for handover prediction calculation, the ICR scheme provides the CRNP to classify the regularity of each mobile terminal and then collect their corresponding handover prediction parameters. Since collecting and deriving the parameters for (1) for calculating the handover prediction (2) is provided in [17], in this section, we focus on deriving the handover parameters from the moving behavior for the handover prediction (3) only.

Let $\langle V_X, E_X, C_{E,X}\rangle$ be the moving behavior of mobile terminal X and X stay in cell C_0 at time t_0. According to the definition of the moving behavior, there may exist zero, one or more than one moving states that may contain cell C_0 in the moving behavior of mobile terminal X. If there is no moving state which contains the cell C_0, then the future location of X is not predictable from its moving behavior [24] and hence the system could adopt the handover prediction (2) only.

Let $V_X(C_0) = \{v = (C, t, s) \in V_X | C$ is the cell ID of $C_0\} = \{v_1, v_2, \cdots, v_n\}$ be the set of all moving states^7, which contain cell C_0, in the moving behavior of X. Finding a moving state, which describes the current time-location status of X, is the first step of deriving the handover parameters when $n > 1$. That is, the CRNP needs a method to find the moving state $v_i \in V_X(C_0)$ such that, for all $v_j \in V_X(C_0), P_r\{(C_0, t_0) \in v_i\} \geq P_r\{(C_0, t_0) \in v_j\}$. $P_r\{(C_0, t_0) \in v\}$ denotes the probability of the event that moving state v is the current time-location status [24] of X and we derive $P_r\{(C_0, t_0) \in v_i\}$ from moving behavior as follows.

We denote $Next(v_i) = \{v_{i,k} \in V_X | (v_i, v_{i,k}) \in E_X\}$.

---

[6] The computational time complexity of the handover prediction (3) is $O(n)$, where n is the number of moving states in $V_x(C_0)$. The term set $V_x(C_0)$ is defined in Section II-C.

[7] For example, whenever an office clerk goes to its office and then goes home, he may pass through the same cell. Thus, there are at least two moving states, which contain the same cell, in the moving behavior of the office clerk.

For convenience, we denote $v_i = (C_i, t_i, s_i)$ and $v_{i,k} = (C_{i,k}, t_{i,k}, s_{i,k})$. Thus, the probability that $(C_0, t_0) \in v_i$ is

$$\begin{aligned} &P_r\{(C_0,t_0) \in v_i\} \\ &= \sum_{v_{i,k} \in Next(v_i)} P_r\{t_i < t_0 < t_{i,k} \text{ and } X \text{ will enter } C_{i,k}\} \\ &= \sum_{v_{i,k} \in Next(v_i)} P_r\{t_i < t_0 < t_{i,k} | X \text{ will enter } C_{i,k}\} \\ &\quad \times P_r\{X \text{ will enter } C_{i,k}\} \\ &= \sum_{v_{i,k} \in Next(v_i)} P_r\{t_i < t_0 < t_{i,k}\} C_E(v_i, v_{i,k}). \end{aligned}$$

We assume the time at which mobile terminal X leaves cell C_0 is independent from the time at which X enters cell C_0. Under this assumption, the two events $\{t_i < t_0\}$ and $\{t_0 < t_{i,k}\}$ are independent. This implies $P_r\{t_i < t_0 < t_{i,k}|X$ will enter $C_{ik}\} = P_r\{t_i < t_0 | X$ will enter $C_{ik}\} \times P_r\{t_0 < t_{i,k}|X$ will enter $C_{ik}\}$

Because t_i and $t_{i,k}$ are all normal variables for all k [24], we have

$$P_r\{(C_0,t_0) \in v_i\} = \sum_{v_{i,k} \in Next(v_i)} \Phi\left(\frac{t_0 - \mu_i}{\sigma_i}\right) \Phi\left(\frac{\mu_{i,k} - t_0}{\sigma_{i,k}}\right) C_E(v_i, v_{i,k}). \quad (4)$$

Whenever a moving state $v_i \in V_X(C_0)$ such that $P_r\{(C_0,t_0) \in v_i\} \geq P_r\{(C_0,t_0) \in v_k\}$ for all $v_k \in V_X(C_0)$ has been determined, the parameters for handover prediction (3) can be set as follows.

1. $P_{X,j} = C_E(v_i, v_{i,j})$ for all adjacent cell $C_j \in v_{i,j} \in Next(v_i)$.
2. $\mu_{X,j} = \mu_{i,j}$ where $\mu_{i,j}$ is the mean of the random variable $t_{i,j} \in v_{i,j}$.
3. $\sigma_{X,j} = \sigma_{i,j}$ where $\sigma_{i,j}$ is the standard deviation of the random variable $t_{i,j} \in v_{i,j}$.

D. Classifying the Moving Regularity for Mobile Terminals

One of the most important functions of the CRNP is the classification which classifies the moving regularity of each active mobile terminal. This is crucial for ICR scheme because the handover parameter of a mobile terminal can only be estimated after the mobile terminal has been determined to have regular or irregular moving behavior. In this subsection, we adopt the same notations, definitions, and assumptions in Section II-C to analyze and propose the classification algorithm.

It is clear that the mobility characteristic of X is irregular if $V_X(C_0)$ is an empty set. If $V_X(C_0)$ is not an empty set, we could not ensure whether the mobility characteristic of X is regular at time t_0. For example, assume the moving behavior of mobile terminal X shows that X often arrives in cell C_0 at time about 2:00PM with standard deviation 5 minutes and then moves to C_1 at time about 3:00PM with standard deviation 6 minutes, then we would believe that X has irregular moving behavior if X appears in cell C_0 at the time 8:00AM. We make this conclusion because X arrives in C_0 too early. In Fig. 5, if X follows its moving behavior, then the probability that $t_0 < T_1$ is less than $\beta/2$. Similarly, the probability that $t_0 > T_2$ is also less than $\beta/2$ because X has probability $1 - \beta/2$ to arrive in C_1 before time T_2 if X follows its moving behavior. Thus, if $t_0 \notin (T_1, T_2)$, then the system has confidence at least $1 - \beta$ to conclude that X has irregular moving behavior at time t_0.

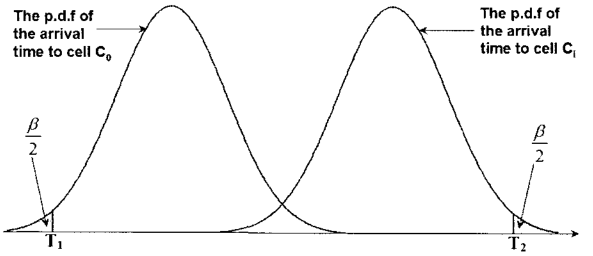


Fig. 5. The confidence intervals for moving irregularity testing.

When $Next(v_i)$ contains more than one moving state, the system could apply the expected value of the T_2 of all the moving states in $Next(v_i)$ to judge the regularity. Based on this point of view, for each mobile terminal staying in cell C_0 at time t_0 and for each $\beta \in (0,1)$, we propose the moving regularity classification (MRC) algorithm below to determine the current mobility regularity for X. In the MRC algorithm, X will be classified as an irregularity if and only if, for all moving states in $V_X(C_0), t_0 \notin (T_1, T_2)$.

Algorithm 1: (MRC Algorithm)[8]

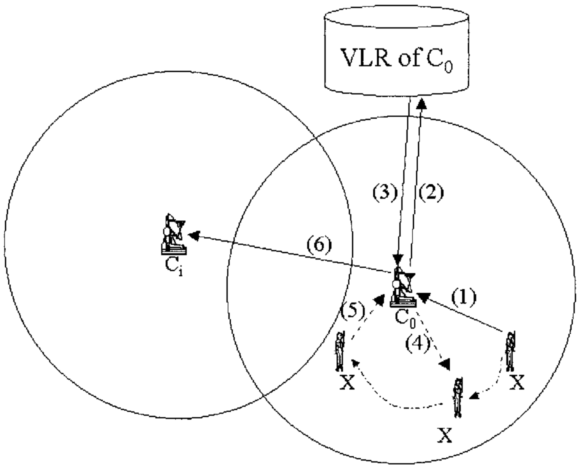
```
Step 1: Determine $V_X(C_0)$ and let $S_X = V_X(C_0)$.
Step 2: If $S_X = \phi$, go to Step 7.
Step 3: Select $v_i = (C_i, \mu_i, \sigma_i s_i) \in S_X$ and let $S_X = S_X - \{v_i\}$
Step 4: Let $T_1 = \sigma_i \times \Phi^{-1}(\beta/2) + \mu_i$, if $t_0 < T_1$, go to Step 2.
Step 5: Let $T_2$ = Mean_Leave_Time($v_i$) (The mean of leaving time of the moving state $v_i$), where
        $\text{Mean\_Leave\_Time}(v_i) = \sum_{v_{i,k} \in Next(v_i)} \left(\sigma_{i,k} \times \Phi^{-1}(1 - \frac{\beta}{2}) + \mu_{i,k}\right) \times C_E(v_i, v_{i,k})$.
        If $t_0 > T_2$, go to Step 2.
Step 6: Classify $X$ to be a regular mobile terminal currently and terminates this algorithm.
Step 7: Classify $X$ to be an irregular mobile terminal currently and terminates this algorithm.
```

III. THE INTELLIGENT CHANNEL RESERVATION SCHEME

By the MRC algorithm, the CRNP is proposed in Section III-A. As the ICR expects that the number of handover connections could be predicted accurately by the GCDM, a new channel assignment algorithm for the ICR is proposed in Section III-B. Through the handover prediction functions, the p.d.f. of the number of the handover connections to each cell in each

---

[8] The computational time complexity of MRC algorithm is O(n), where n is the number of moving states in $V_x(C_0)$.



Step 1. X gets connection to the BS of C_0.
Step 2. C_0 queries its VLR to get the current moving behavior of X.
Step 3. If X is a regular mobile terminal, C_0 will calculate the handover parameters of X from its current moving behavior and then go to Step 6. Otherwise, go to Step 4.
Step 4. C_0 requires X to submit its handover parameters.
Step 5. X submits its handover parameters to C_0.
Step 6. C_0 submits the handover parameters of X to all the corresponding cells.

Fig. 6. The channel reserving announcement procedure.

time interval is derived in Section III-C. To reserve guard channels accurately, in Section III-C, a cost function which maps the number of idle channels and the number of expected handover blocked connections into a cost value and an algorithm which minimizes the cost function are proposed for the GCDM to determine the number of guard channels.

A. The CRNP

A.1 Reservation Announcement

Whenever a mobile terminal X which handovers to the cell of C_0 or initiates a new connection to the cell of C_0, the base station first retrieves the current moving behavior, which contains the set $V_X(C_0)$, $Next(v_i)$ for all $v_i \in V_x(C_0)$, and the function $C_E(v_i, v_{i,j})$ for all $v_{i,j} \in Next(v_i)$, from its VLR[9] (visitor location register) [24]. Once the MRC algorithm judges that X is an irregular mobile terminal currently, X is required to submit the parameters of its handover prediction (2) to its base station. Otherwise, cell C_0 calculates the parameters for the handover prediction (3) of X. Whenever the parameters of the handover prediction of X are derived, the cell C_0 sends the parameters to all its adjacent cells. Fig. 6 shows the CRNP of the ICR scheme.

In Fig. 6, whenever a mobile terminal X gets connection to its base station (Step 1), the base station of C_0 queries its VLR to get the current moving behavior of X (Step 2 and Step 3). If the MRC algorithm determines that X is an irregular mobile terminal currently, then cell C_0 requires X to collect a sequence of time-location events and then estimate the parameters of its handover prediction (2) (Step 4). After X collects enough time-position events[10] and estimates the parameters D_x, D_y, v_x, and v_y for the handover prediction, it sends the parameters to its base station (Step 5). Whenever its base station gets the parameters of its handover prediction, its base station forwards all the parameters to its adjacent cells (Step 6).

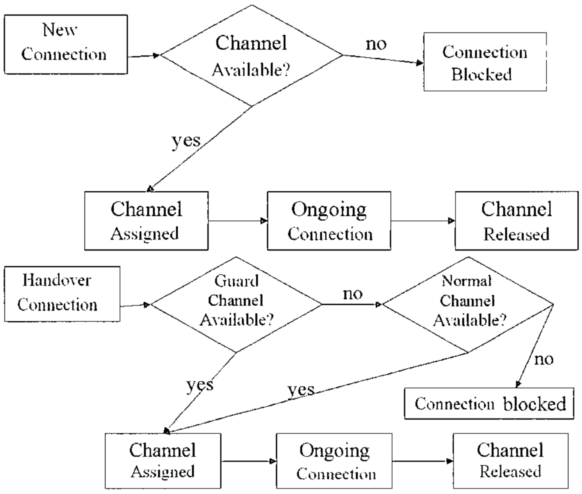


Fig. 7. The channel assignment procedures of ICR.

If the MRC algorithm determines that X is a regular mobile terminal currently, the base station of X calculates the parameters $\{(P_{X,i}, \mu_{X,i}, \sigma_{X,i}) \in V_X(C_i) | C_i$ is an adjacent cell of $C_0\}$ for the handover prediction (3) according to the formulas proposed in Section II-C. In this situation, the base station of cell C_0 sends the parameters to the corresponding cells directly (Step 6) without Step 4 and Step 5.

A.2 Reservation Cancellation

A reservation may become invalid. For example, whenever a connection is terminated or an active mobile terminal handovers to another cell, the corresponding reservation becomes invalid. In this situation, the corresponding reservations must be cancelled to avoid the consequence of reserving unnecessary guard channels. Whenever a base station senses that a connection is disconnected or an active mobile terminal handovers to another cell, the ICR scheme requires the base station to send a signal to the corresponding base stations. Whenever a base station receives a cancellation from other base station, it cancels the reservation by removing the corresponding handover parameters.

B. Channel Assignment Procedure

Fig. 7 shows the channel assignment procedures of the ICR scheme. The available channels of a cell are divided into two categories called the normal channels and the guard channels. The guard channels could only be assigned to handover connections.

---

[9] If its VLR does not maintain the current moving behavior of X, then the VLR will retrieve the current moving behavior of X from the HLR of X.

[10] A time-position event for an active mobile terminal X is a 3-tuple (t, x, y), which shows that X is in (x, y) at time t.

Whenever a mobile terminal initiates a new connection, its base station will assign a channel to it if and only if there are available normal channels. Otherwise, the new connection is blocked. Whenever a mobile terminal handovers to a cell, distinct from the traditional RCS protocols, the base station of the cell first checks whether there are available guard channels. If there are available guard channels, a guard channel will be assigned to the mobile terminal. If there is no available guard channel, then the base station checks whether there are available normal channels. If there are available normal channels, then the base station assigns a normal channel to the mobile terminal, otherwise, the handover connection is blocked. Under this channel assignment procedure, if the GCDM reserves channels accurately, then it is expected that there are no idle channels and the new connection will not need to compete with the handover connections for normal channels.

C. The Guard Channel Decision Maker

Channel reservation schemes will consider carefully two measurements: The expected blocked handover connections and the expected idle channels. A guard channel is said to be an idle channel in time interval (t_0, t) if it is not assigned to any active mobile terminal in this time interval. The goal of the GCDM is to minimize the expected number of idle channels and the expected number of blocked handover connections simultaneously. To determine the appropriate number of guard channels for each cell according to the handover predictions, for each future time $t > t_0$, we make several notations and assumptions for the cell C_i as follows.

C.1 Notations

- F_i: The number of available channels.
- $\{V_1, V_2, \cdots, V_{M(i)}\}$: The set of all handover parameters collected by the cell C_i where $V_j = \langle X(j), P_{X(j),i}, \mu_{X(j),i}, \sigma_{X(j),i}\rangle$ or $\langle X(j), D_x, D_y, v_x, v_y\rangle$ for all $1 \leq j \leq M(i)$.
- $$Y_{ij}(t_0, t) = \begin{cases} 1, & \text{if } X(j) \text{ will arrive in the cell } C_i \\ & \text{between time } t_0 \text{ and } t \\ 0, & \text{otherwise.} \end{cases}$$
- $HC_i(t_0, t)$: The number of active mobile terminals that will handover to C_i in the time interval (t_0, t).
- $HR_i(t_0, t)$: The number of guard channels reserved in the time interval (t_0, t).

C.2 Assumptions

- The random variables $Y_{ij}(t_0, t)$ and $Y_{ik}(t_0, t)$ are independent for all $1 \leq j \neq k \leq M(i)$. That is, the event that the mobile terminal $X(j)$ will arrive in C_i in the time interval (t_0, t) is independent to the event that the mobile terminal $X(k)$ will arrive in C_i in the time interval (t_0, t).

It is clear that $HC_i(t_0, t) = \sum_{j=1}^{M(i)} Y_{ij}(t_0, t)$ and $P_r(Y_{ij}(t_0, t) = 1) = HP(X(j), C_i, t_0, t)$. With the above notations and assumptions, we assume random variable $HC_i(t_0, t)$ is a normal random variable with mean $\mu_i(t_0, t) = \sum_{j=1}^{M(i)} HP(X(j), C_i, t_0, t)$ and standard deviation $\sigma_i(t_0, t) = \sqrt{\sum_{j=1}^{M(i)} HP(X(j), C_i, t_0, t)(1 - HP(X(j), C_i, t_0, t))}$ according to the Theorem 2 in the appendix. Therefore, the expected number of handover connections to compete with new connections for the available normal channels and the expected idle channels in time interval (t_0, t) could be estimated by (5) and (6), respectively.

$$EHCN_i(t_0, t) = \\ \frac{\int_{HR_i(t_0,t)}^{\infty} (y - HR_i(t_0, t)) \exp(\frac{(y-\mu_i(t_0,t))^2}{2\sigma_i(t_0,t)}) dy}{\sqrt{2\pi\sigma_i(t_0, t)}}, \tag{5}$$

$$EIC_i(t_0, t) = \\ \frac{\int_{0}^{HR_i(t_0,t)} (HR_i(t_0, t) - y) \exp(\frac{(y-\mu_i(t_0,t))^2}{2\sigma_i(t_0,t)}) dy}{\sqrt{2\pi\sigma_i(t_0, t)}}. \tag{6}$$

The priorities of minimizing (5) and (6) may have different consideration factors. Thus, we propose a cost model for the GCDM to determine the number of guard channels for cell C_i in time interval (t_0, t) as follows.

Min $EHCN_i(t_0, t) + \alpha EIC_i(t_0, t)$. (7)
Subject to $0 \leq HR_i(t_0, t) \leq F_i$ and $HR_i(t_0, t)$ is an integer.
Where $\alpha \geq 0$ is the weight for the idle channels.

Because $0 \leq HR_i(t_0, t) \leq F_i$ and $HR_i(t_0, t)$ is an integer, whenever the parameters t_0, t and α are given, the optimal solution of (7) could be easily found. In other words, minimizing (7) could be achieved through exhaustive search with the complexity $O(M(i) \times n)$, where n is the number of channel resources maintained by the corresponding base station.

IV. EXPERIMENTS AND COMPARISON

In this section, we evaluate the ICR scheme via comparing it with the PCR_2 protocol [2] and the non-predictive fixed guard channel (GC) protocol through the simulation methods. The PCR_2 protocol applies the tangent velocity of each active mobile terminal to predict the next candidate hand-off cell. In other words, the next candidate hand-off cell for an active mobile terminal is the first adjacent cell in which the projection path of the active mobile terminal passes through. If an active mobile terminal terminates its connection before it arrives to its next cell, a cancellation of the previous reservation will be initiated to de-allocate the reserved channel. As the next cell of an active mobile terminal is changed, not only a cancellation of the previous reservation will be initiated, but also a new reservation will be held in its corresponding new next cell. To further reduce the number of false reservations, the PCR_2 protocol proposes the concept of threshold distance (TD). If the distance from an active mobile terminal to its base station is larger than TD, no channel reservation requests are initiated by its base station.

A. Simulation Design

A.1 Environment Design and Mobility Model

All the simulations are performed on a 5 × 5 cellular network. In the simulations, the radius of the coverage area of each cell is 1000 meters, the number of mobile terminals is 1000, the number of guard channels for GC protocol is set to be 6, the length of the time interval for the cost model (7) is 20 seconds, the value of β for the MRC algorithm is set to be 0.05 and the TD [2] is 600 meters. Each mobile terminal has the probability of 0.7[11] (e.g., 5 days /week $\approx$ 0.7) to be classified as a regular mobile terminal. If a mobile terminal is classified as a regular mobile terminal, the system assigns a handover parameter to it. For a mobile terminal X with handover parameter $\langle X, P_{X,i}, \mu_{X,i}, \sigma_{X,i}\rangle$, the values of $P_{X,i}$ is randomly assigned satisfying $P_{X,1} + \cdots + P_{X,M(i)} = 1$ where $M(i)$ may be 1, 2, or 3. The experiments apply an exponential random variable with the mean value of μ to generate the values of $\mu_{X,j} - t_0$, and then apply another exponential random variable with the mean value of σ to generate the values of the parameter $\sigma_{X,j}$. For convenience, the value σ^2 is set as $\mu/2$ in the simulation experiments.

Each regular mobile terminal moves according to the rules below. Let L_X be the location at which the system assigns a handover parameter to mobile terminal X. The next cell of mobile terminal X is chosen according to the probabilities list $\langle P_{X,j}\rangle$. If mobile terminal X chooses cell C_i to be the next cell, then the system randomly chooses a point L'_X in the cell C_i and then X follows the 2-dimensional Brownian motion with drift parameter (v_x, v_y) and diffusion parameter (D_x, D_y) to move toward L'_X. The norm of the velocity (v_x, v_y) is $\parallel L'_X - L_X \parallel / (\mu_{X,j} - t_0)$ where $\parallel L'_X - L_X \parallel$ is the distance between L_X and L'_X, and the norm of the diffusion (D_x, D_y) is $\sigma^2_{X,j}$. Whenever X moves to another cell, the system applies the same rule to determine the moving regularity of X again.

If a mobile terminal is classified as an irregular mobile terminal, the mobile terminal moves according to the 2-dimensional Brownian motion with a drift parameter (v_x, v_y) and a diffusion parameter (D_x, D_y). The system applies the following steps to determine the values of the parameters. First, the system randomly selects a value θ from the interval $(0, 2\pi)$. Second, the system applies an exponential random variable whose mean is $1000/\mu$ to generate a value for variable ν, and then applies another exponential random variable whose mean is σ^2 to generate a value for the variable Ω. Third, whenever the values of variables θ, ν, and Ω are determined, the system sets $(v_x, v_y) = (\nu\cos\theta, \nu\sin\theta)$ and $(D_x, D_y) = (\Omega\cos\theta, \Omega\sin\theta)$. Whenever the mobile terminal moves to another cell, the system applies the same rule to determine the moving regularity of the mobile terminal again.

A.2 Traffic Model

The duration of each connection is an exponential random variable with mean = 180 seconds. In each time interval, each non-active mobile terminal has probability $\wp$ to initiate a new connection. The number of channels allocated to each cell is 36. We adopt the definition in [2] to define the traffic load of each cell below.

$$\frac{\text{Arrival Rate to The Cell} \times \text{Average Call Duration}}{\text{Number of Channels Per Cell}} \times 100\%$$

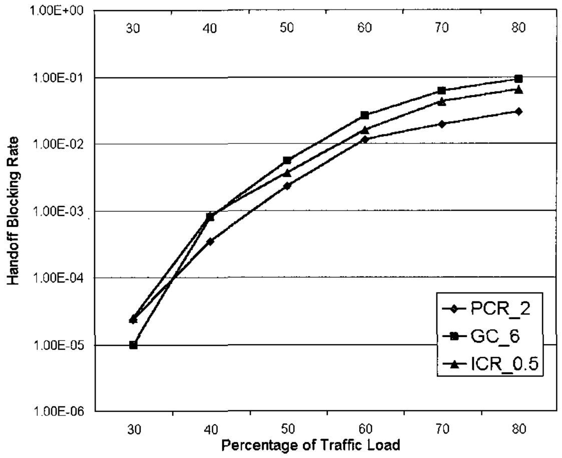


Fig. 8. Handover blocking rate at various traffic loads.

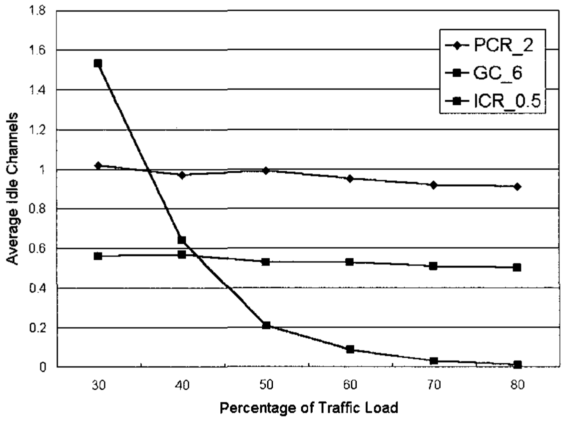


Fig. 9. Average idle channels at various traffic loads.

According to the definitions above, whenever the value of the traffic load TL is determined, the value of $\wp$ is defined to be $TL/10$.

B. *Experiment Results and Comparisons*

According to the cost function (7), the number of channels reserved by the ICR protocol is expected to be less than that reserved by the PCR_2 protocol in general when $\alpha > 0$. In this situation, it is desirable to know how many idle channels are released by the ICR scheme and whether the handover blocking rate of this protocol is acceptable. The first experiment compares the handover blocking rates and the numbers of idle channels for the three protocols at various traffic loads with the same mobility generator $1/\mu$ = 0.015. Because the event of blocking a handover connection seldom occurs in the experiments with low traffic load, therefore, each value in Fig. 8 is a statistic of 100000 handover events. In Figs. 9–13, results are calculated from at least 500 handover events.

The results in Fig. 8 show that the handover-blocking rates of PCR_2 protocol are generally lower than that introduced by our proposed ICR_0.5[12] protocol. Although the handover blocking

---

[11] From the theoretical point-of-view, the number of guard channels is independent to the value of moving regularity. Therefore, the experiments do not evaluate the performance for different moving regularity.

[12] The number of guard channels reserved by ICR_A protocol is decided by

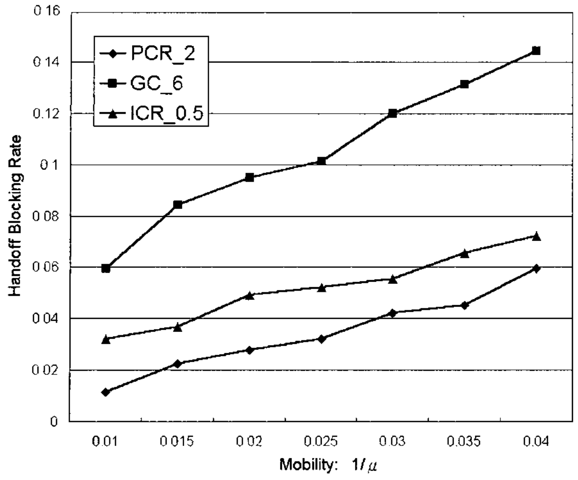


Fig. 10. Handover blocking rates at various mobility generators.

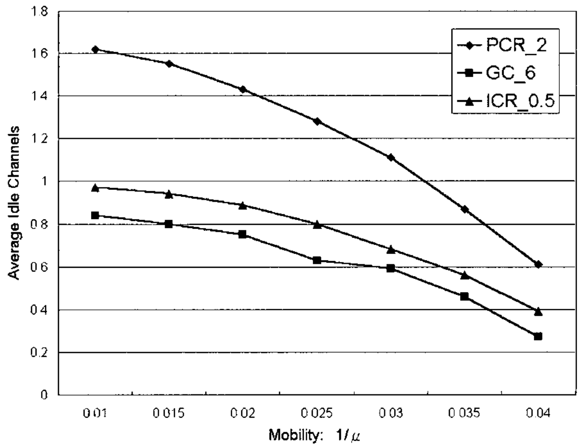


Fig. 11. Average idle channels at various mobility generators.

rate of the ICR_0.5 protocol is not better than the PCR_2 protocol, however, the performance differences of the three protocols are minute and it hence shows that the handover blocking rate of the ICR_0.5 protocol is acceptable at various traffic load. Moreover, according to Fig. 9, the ICR_0.5 scheme brings less number of idle channels than the PCR_2 protocol in general. This experiment demonstrates that the number of guard channels reserved by the ICR_0.5 protocol is more accurate than the other two protocols.

In the second experiment, we continue to compare the handover blocking rates and the numbers of idle channels for the three protocols at various mobility generators under the same traffic load value of 80%. Since the events of handover blocking and new connections blocking seldom occur in the low-traffic load situation, this experiment compares the performance of the three protocols in such a high-traffic load condition.

Figs. 10 and 11 show the handover blocking rate and the number of idle channels of the three protocols at various mobility generators. Fig. 10 shows that the PCR_2 and ICR_0.5 protocols bring much lower handover blocking rates than GC_6 at various mobility generators because the GC_6 reserves insufficient guard channels. This also shows that the handover blocking rate introduced by the ICR_0.5 protocol is acceptable. On the other hand, Fig. 11 shows that the ICR_0.5 brings less number of idle channels than the PCR_2 protocol in general. Therefore, this experiment also shows that the number of guard channels reserved by the ICR_0.5 protocol is more accurate than the other two protocols at high traffic load condition.

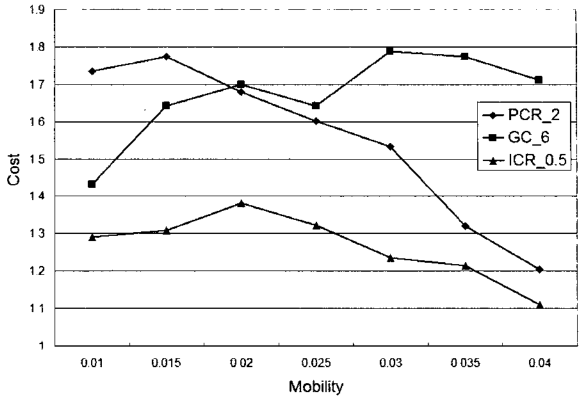


Fig. 12. Cost distributions at various mobility generators.

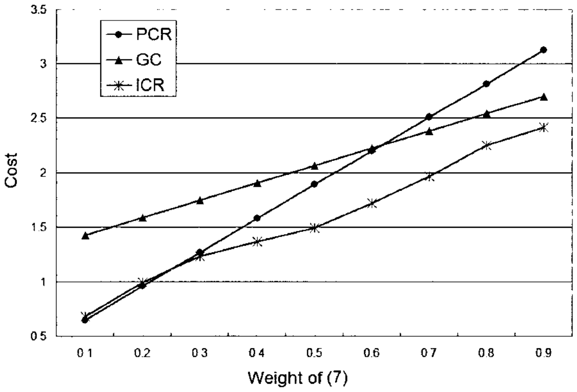


Fig. 13. Cost distribution at various values of α.

To compare the three protocols in the two dimensions (number of blocked handover connections and idle channels) simultaneously, we adopt the cost function (7) to compare them in the third experiment. Similarly, we only consider the scenarios with heavy traffic load. Since the traffic load is heavy, the value of α should be large enough to reduce the number of idle channels. Fig. 12 shows the costs of the three protocols at various mobility generators in the same traffic load 80%. The comparison shows that the ICR protocol performs much better than the other two protocols, PCR_2 and GC when $\alpha = 0.5$ in the terms of the cost function (7).

Fig. 13 compares the costs of the three protocols at various values of α (the weight of the cost function (7)) with fixed mobility generator $1/\mu = 0.015$ and traffic load value 80%. According to the cost function (7), we expect that ICR_α reserves more channels for handover connections as the value of α decreases. When the value of α becomes 0, ICR_α will not consider the damages arisen from the idle channels and hence acts as the PCR_2 protocol. When the value of α increases, the ICR_α protocol takes the idle channels into account and then

the cost model (7) with weight $\alpha = A$.

reserves less channel resources for the handover connections. Fig. 13 shows that the intelligent mechanism makes the cost of the ICR schemes lower then the other two protocols when α increases.

The difficulty of handover handling increases with the traffic load of the network since the competitions for bandwidth resources are much keener in this condition. When the traffic load becomes heavy, the bandwidth resource requests from both handover connections and new connections are huge. In this situation, channel reservation should be more conservative. That is, the value of α in the cost function (7) should not be small. According to the Fig. 13, the ICR performs significantly better than the other two protocols when $\alpha > 0.3$. It shows that the proposed scheme could improve the quality of bandwidth resource managements in heavy loaded cellular networks.

C. Discussion

The handover prediction mechanism of the ICR scheme is based on the success of location prediction technologies. To reduce the huge computation complexity and resources for positioning, the ICR scheme employs the profile-based approach to estimate the handover prediction for mobile terminals with regular moving behavior. Since the moving regularity of individual mobile terminals is determined by the MRC algorithm, the accuracy of the MRC algorithm and the prediction algorithm both are critical for the performance of the ICR scheme.

This paper is devoted to demonstrating the performance of the ICR scheme based on the assumptions that the classification and prediction algorithms are accurate enough. In current stage, the accuracy of the proposed positioning technologies is not high enough for location prediction; however, many current researches seek to increase the accuracy of positioning and hence we expect that the positioning technologies provided in the next generation personal communication networks will be accurate enough for the ICR.

According to the inference in Section II-D, we conclude that the accuracy of the parameters of moving behavior decides the accuracy of the MRC algorithm. Although the study [24] shows that the accuracy of the parameters of each moving behavior increases with the number of moving logs which generate the moving behavior, however, evaluating the accuracy of moving behavior is still a great challenge since the accuracy of moving behavior could be only evaluated and justified by the daily real world cellular subscriber moving histories. The continuous efforts will go evaluating the classification algorithms for the future research work.

The experimental results in Fig. 13 show that the cost of PCR performs as well as the ICR when α is small (less than 0.3). Since the PCR simply applies the tangent velocity for handover prediction, the computational cost is significantly lower than the ICR scheme. Therefore, either applying the PCR scheme for mobile terminals with irregular moving behavior or improving the original mobility model of the ICR scheme with the tangent velocity mobility model would further reduce the computational cost. However, the mobility model taken by the PCR is rough; therefore, the further research will investigate on reducing the computational cost through searching some approximate calculations for (1) and (2) with low computational cost.

V. CONCLUSIONS

This paper introduces a novel handover scheme called the intelligent channel reservation scheme, which employs the location prediction technologies to accurately reserve channel resources for handover connections. The main contributions of the paper are summarized as follows.

1. Propose the MRC algorithm to determine the current moving regularity of each mobile terminal. This is a key algorithm for the behavior based strategies [24] since it provides a test for the system to determine whether the system should continue to adopt the prediction from the moving behavior of the mobile terminal or not.
2. Propose the CRNP to intelligently collect appropriate handover prediction parameters of the active mobile terminals according to their current moving regularity and their moving behaviors. It will contribute to providing the behavior based approaches to the mobile terminal with regular moving behavior currently and providing the tangent velocity approaches to the others.
3. Propose a novel handover prediction for the next generation personal communication to facilitate the task of determining the appropriate number of guard channels for the GCDM.
4. Apply the central limit theorem to estimate the p.d.f. for the number of handover connections according to the handover predictions of the active mobile terminals near by. With the help of the p.d.f., the GCDM for the next generation personal communication systems can determine a number of guard channels which minimizes the cost function (7).

The experimental results demonstrate that the ICR scheme successfully integrates the tangent velocity and the behavior based location prediction technologies, and achieves the goal of reducing the handover-blocking rate while keeping the number of idle channels small.

The proposed strategies focus on the applications for the next generation wireless networks, we expected that the computation power of each component of each cellular system will be improved significantly and the radio resources are still limited and hence become more precious than the computation resources. Although the complexity of our proposed algorithms is not low enough, however, the main computing parameters, the domain sizes of the optimization problem (7) will be reasonably few since each base station only offers a limited number of channels. Therefore, the computational complexity of our proposed algorithms would be acceptable for the new generation cellular networks.

ACKNOWLEDGMENT

This work was supported by the MediaTek, Inc. under the project "Wireless Communication Systems". This work was also supported by National Science Council of Taiwan under the NSC93-2524-S-008-002 Integrated knowledge Management Project.

APPENDIX

Theorem 1: Let C_0 be a cell and $C_1, C_2, \cdots, C_K$ be all its adjacent cells. If the mobile terminal X stays in C_0 at time t_0 and X follows its moving behavior, then

$$HP(X, C_j, t_0, t) = \begin{cases} 0, & \text{if } t \le t_0 \\ \dfrac{\Phi\left(\dfrac{t-\mu_{X,j}}{\sigma_{X,j}}\right) - \Phi\left(\dfrac{t_0-\mu_{X,j}}{\sigma_{X,j}}\right)}{1-\Phi\left(\dfrac{t_0-\mu_{X,j}}{\sigma_{X,j}}\right)} \times P_{X,j}, & \text{otherwise,} \end{cases}$$

where

- $P_{X,j}$ denotes the probability that X will pass through cell C_j.
- $\mu_{X,j}$ and $\sigma_{X,j}$ are the mean and standard deviation of the arrival time that mobile terminal X will arrive in C_j.
- $\Phi(\cdot)$ denotes the cumulative distribution function (c.d.f.) of the standard normal random variable.

Proof: By definition, $HP(X, C_j, t_0, t) = P_r\{X$ will arrive in C_j and X arrives in C_j at some time before $t|X$ stays in C_0 at time $t_0\} = P_r\{X$ arrives in C_j before time $t|X$ will arrive in C_j and X stays in C_0 at time $t_0\} \times P_r\{X$ will arrive in $C_j\}$. Let Y be the time X arrives in C_j given X will arrive in C_j. Because X follows its moving behavior is assumed, Y is a the normal random variable with parameters $\mu_{X,j}$ and $\sigma_{X,j}$ [24]. And hence, we have

$$P_r\{X \text{ arrives in } C_j \text{ before time } t|X\text{will arrive in } C_j \text{ and } X \text{ stays in} C_0 \text{at time} t_0\} = P_r\{Y < t|Y \ge t_0\} = \frac{P_r\{t_0 \le Y < t\}}{P_r\{Y \ge t_0\}} = \frac{\Phi\left(\dfrac{t-\mu_{X,j}}{\sigma_{X,j}}\right) - \Phi\left(\dfrac{t_0-\mu_{X,j}}{\sigma_{X,j}}\right)}{1-\Phi\left(\dfrac{t_0-\mu_{X,j}}{\sigma_{X,j}}\right)}.$$

Let $P_{X,j} = P_r\{X$ will arrive in $C_j\}$, we have, for $t > t_0$,

$$HP(X, C_j, t_0, t) = \frac{\Phi\left(\dfrac{t-\mu_{X,j}}{\sigma_{X,j}}\right) - \Phi\left(\dfrac{t_0-\mu_{X,j}}{\sigma_{X,j}}\right)}{1-\Phi\left(\dfrac{t_0-\mu_{X,j}}{\sigma_{X,j}}\right)} P_{X,j}.$$

This completes the proof of Theorem 1. □

Theorem 2: If, for each $1 \le j \ne k \le M(i)$, the two random variables $Y_{ij}(t_0, t)$ and $Y_{ik}(t_0, t)$ are independent, then

$$P_r\left\{\frac{HC_i(t_0, t) - \mu_i(t_0, t)}{\sigma_i(t_0, t)} \le a\right\} \to \Phi(a) \text{ as } M(i) \to \infty,$$

where

$$\mu_i(t_0, t) = \sum_{j=1}^{M(i)} HP(X(j), C_i, t_0, t),$$

$$\sigma_i(t_0, t) = \sqrt{\sum_{j=1}^{M(i)} HP(X(j), C_i, t_0, t)(1 - HP(X(j), C_i, t_0, t))}.$$

Proof: It is clear that $Y_{ij}(t_0, t)$ are all uniformly bounded. Because $0 < E[Y_{ij}(t_0, t)] < 1, Var(Y_{ij}(t_0, t)) = E[Y_{ij}(t_0, t)] \times (1 - E[Y_{ij}(t_0, t)]) \ne 0$ is also clear. This implies $\lim_{M(i)\to\infty} \sum_{j=1}^{M(i)} Var(Y_{ij}(t_0, t)) = \infty$. Because $Y_{i1}(t_0, t), Y_{i2}(t_0, t), \cdots, Y_{iM(i)}(t_0, t)$ forms a sequence of independent random variables, according to the central limit theorem for independent random variables [25], [26], we have

$$P\left\{\frac{\sum_{j=1}^{M(i)}(Y_{ij}(t_0, t) - E[Y_{ij}(t_0, t)])}{\sqrt{\sum_{j=1}^{M(i)} Var(Y_{ij}(t_0, t))}}\right\} \to \Phi(a) \quad \text{as } M(i) \to \infty.$$

By the definition of $Y_{ij}(t_0, t)$, $E[Y_{ij}(t_0, t)]$ is the probability that the mobile terminal $X(j)$ will arrive C_i in the time interval (t_0, t). Thus, by the definition of handover prediction, $E[Y_{ij}(t_0, t)] = HP(X(j), C_i, t_0, t)$ and $Var(Y_{ij}(t_0, t)) = HP(X(j), C_i, t_0, t)(1 - HP(X(j), C_i, t_0, t))$. This completes our proof. □

REFERENCES

[1] R. Berezdivin, R. Breinig, and R. T. Raytheon, "Next generation wireless communications concepts and technologies," *IEEE Commun. Mag.*, vol. 40, pp. 108–116, Mar. 2002.

[2] M. H. Chiu and M. A. Bassiouni, "Predictive schemes for handoff prioritization in cellular networks based on mobile positioning," *IEEE J. Select. Areas Commun.*, vol. 18, pp. 510–522, Mar. 2000.

[3] D. A. Levine, I. F. Akyldiz, and M. Naghshineh, "A resource estimation and cell admission algorithm for wireless multimedia networks using the shadow cluster concepts," *IEEE/ACM Trans. Networking*, vol. 5, pp. 1–12, Feb. 1997.

[4] I. Chlamtac, T. Liu, and J. Carruthers, "Location management for efficient bandwidth allocation and call admission control," in *Proc. IEEE WCNC'99*, 1999, pp. 1023–1027.

[5] E. V. den Berg *et al.*, "Time series-based localized predictive resource reservation for handoff in multimedia wireless networks," in *Proc. IEEE ICC 2001*, 2001, pp. 346–350.

[6] S. S. Wang and C. H. Wu, "Effective handoff method using mobile location information," in *Proc. IEEE VTC 2001*, vol. 4, 2001, pp. 2585–2589.

[7] W. Li and A. S. Alfa, "Channel reservation for handoff calls in a pcsPCS network," *IEEE Trans. Veh. Technol.*, vol. 49, pp. 95–104, Jan. 2000.

[8] H. G. Ebersman and O. K. Tonguz, "Handover ordering using signal prediction priority queuing in personal communication systems," *IEEE Trans. Veh. Technol.*, vol. 48, pp. 20–35, Jan. 1999.

[9] J. Li, N. B. Shroff, and E. K. P. Chong, "Channel carrying: A novel handoff scheme for mobile cellular networks," *IEEE/ACM Trans. Networking*, vol. 7, pp. 38–50, Feb. 1999.

[10] R. Ramjee, R. Nagarajan, and D. Towsley, "On optimal call admission control in cellular networks," in *Proc. IEEE INFOCOM'96*, 1996, pp. 43–50.

[11] T. Zhang, P. Agrawal, and J. C. Chen, "IP-based base stations and soft handoff in all-IP wireless networks," *IEEE Pers. Commun.*, pp. 24–30, Oct. 2001.

[12] V. C. S. Lee, K. W. Lam, and S. H. Son, "Real-time transaction processing with partial validation at mobile clients," in *Proc. the 7th International Conference on Real-Time Computing Systems and Applications*, 2000, pp. 473–477.

[13] E. Kayan and O. Ulusoy, "Real-time transaction management in mobile computing systems," in *Proc. the 6th International Conference on Database Systems for Advanced Applications*, 1999, pp. 127–134.

[14] A. Misra *et al.*, "IDMP-based fast handoffs and paging in IP-based 4G mobile networks," *IEEE Commun. Mag.*, vol. 40, pp. 138–145, Mar. 2002.

[15] M. Naghshineh and M. Schwartz, "Distributed call admission control in mobile/wireless networks," *IEEE J. Select. Areas Commun.*, vol. 14, pp. 711–717, May 1996.

[16] O. T. W. Yu and V. C. M. Leung, "Adaptive resource allocation for prioritized call admission over an ATM-based wireless PCN," *IEEE J. Select. Areas Commun.*, vol. 15, pp. 1208–1225, Sept. 1997.

[17] Z. Lei, C. U. Saraydar, and N. B. Mandayam, "Mobility parameter estimation for the optimization of personal paging areas in PCS/cellular mobile networks," in *Proc. IEEE Workshop on Signal Processing Advances in Wireless Communications*, May 1999, pp. 308–312.

[18] S. Saltenis *et al.*, "Indexing the positions of continuously moving objects," in *Proc. ACM SIGMOD Conf.*, 2000, pp. 331–342.

[19] T. Liu, P. Bahl, and I. Chlamtac, "Mobility modeling, location tracking, and trajectory prediction in wireless atm networks," *IEEE J. Select. Areas Commun.*, vol. 16, Aug. 1998.

[20] B. Hofmann-Wallehnhof, H. Lichtenegger, and J. Collins, *Global Positioning System: Theory and Practice*, New York: Springer-Verlag, 1997.

[21] M. Hellebrandt, R. Mathar, and M. Scheibenbogen, "Estimating position and velocity of mobiles in a cellular radio network," *IEEE Trans. Veh. Technol.*, vol. 46, Feb. 1997.

[22] S. Tabbane, "An alternative strategy for location tracking," *IEEE J. Select. Areas Commun.*, vol. 13, pp. 880–892, June 1995.

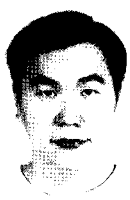
[23] G. P. Pollini and C.-L. I, "A profile-based location strategy and its performance," *IEEE J. Select. Areas Commun.*, vol. 15, pp. 1415–1424, Oct. 1997.

[24] H. K. Wu *et al.*, "Personal paging area design based on mobile's moving behaviors," in *Proc. INFOCOM 2001*, 2001, pp. 21–30.

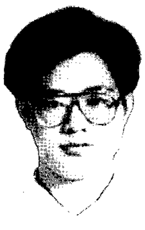
[25] E. R. Dougherty, *Probability and Statistics for the Engineering, Computing and Physical Sciences*, Prentice-Hall International, Inc.

[26] S. Ross, *A First Course in Probability, 5th ed.*, Prentice-Hall International, Inc.

Ming-Hui Jin received his B.S. degree in mathematics from National Central University in 1995. He received his Ph.D. in computer science from National Central University in 2003. He is a post doc of Computer Science and Information Engineering at National Taiwan University. His primary research interests include Wireless Sensor Networks, Mobile Computing, and Database System.



Eric Hsiao-kuang Wu received his B.S. degree in computer science and information engineering from National Taiwan University in 1989. He received his Master and Ph.D. in computer science from University of California, Los Angeles (UCLA) in 1993 and 1997, respectively. He is an Associate Professor of Computer Science and Information Engineering at National Central University, Taiwan. His primary research interests include Wireless Networks, Mobile Computing, and Broadband Networks. He is a member of IICM (Institute of Information and Computing Machinery) and IEEE.



Chao-Hsu Chang received his B.S. and M.S. degree in computer science and information engineering from the Feng Chia University, Taiwan, in 1991 and 1993, respectively. In 1993, he joined the Department of Information Management at National United University as a lecturer. Currently, he is a Ph.D. candidate in the Department of Computer Science and Information Engineering at National Central University, Taiwan. His research interests include Satellite Networks, Multicasting, and Wireless Networks.