An adaptive resource reservation strategy for handoff in wireless CDMA cellular networks

Une stratégie adaptative de réservation de ressource pour le transfert en fondu dans les réseaux cellulaires sans fil à AMDC

Jinfang Zhang, Jon W. Mark, and Xuemin Shen*

A threshold-based adaptive resource reservation scheme for soft handoff calls in wireless code division multiple access (CDMA) cellular networks is proposed. The scheme gives handoff calls a higher admission priority than new calls, and is designed to adaptively adjust the reservation-request time threshold according to the varying traffic load. The individual reservation requests form a common reservation pool, and handoff calls are served on a first-come, first-served basis. With the proposed scheme, a minimum grade of service (GoS) in terms of new call blocking and handoff call dropping probabilities can be achieved. Simulation results are given to demonstrate the improvement in the GoS performance in comparison with other schemes.

On propose un arrangement adaptatif de réservation de ressource basé sur le seuillage pour les transferts en fondu dans les réseaux cellulaires multiples à accès multiple par division de code (AMDC). L'arrangement donne aux transferts en fondu une priorité d'admission supérieure par rapport aux nouveaux appels et est conçu pour ajuster le temps de demande de réservation de manière adaptative selon la quantité de trafic. Les demandes de réservation individuelles forment une banque commune de réservation, et les transferts en fondu sont servis selon le mode premier-arrivé, premier-servi. Avec l'arrangement proposé, une certitude minimum du service (CMS) est obtenue en termes de probabilités de blocage de nouveaux appels et de pertes de transferts en fondu. Des résultats de simulation sont donnés pour démontrer l'amélioration de la performance de la CMS par rapport à d'autres arrangements.

Keywords: adaptive resource reservation, grade of service, mobility model, soft handoff, wireless CDMA

I. Introduction

With the growing high degree of user mobility expected in future wireless code division multiple access (CDMA) networks, handoff will play a paramount role in the networks' provision of seamless service to mobile users anywhere at any time. Handoff is a process whereby a mobile station (MS) communicating with one base station (BS) is transferred to another BS. The mobile call might be forced to abort during the handoff if it cannot be allocated sufficient resources in the new cell. From a user's perspective, forced termination of an ongoing call due to handoff is more undesirable than blocking of a newly arrived call.

Resource reservation is an efficient way to provide handoff calls a higher admission priority than new calls. Most research in resource reservation has focused on analytical approaches with the assumption of exponentially distributed cell residence time, which is also the inter-handoff time. However, the exponential inter-handoff time assumption underestimates the handoff rate, which leads to an actual dropping probability higher than that designed for cellular networks [1]. Measurement-based resource reservation approaches have received a lot of attention because of their ability to capture the nonstationary characteristics of user mobility, propagation loss, traffic load, and so on [2]–[3]. With the assumption of strong correlation between the present and the past handoff events in a cell, a history-based adaptive resource reservation and admission control scheme is proposed in [2]. The performance of this scheme depends mainly on system stability. Also, this scheme cannot track the random varying traffic load and mobility variations. In addition, new call blocking probability and system resource utilization are not taken into account. Reference [4] proposes a threshold distance within which a resource reservation request is sent to the target BS. The propagation model considers only path loss, while no fast fading and slow shadowing effects are taken into account. Reference [5] considers user velocity as well as positioning, and proposes a scheme based on the remaining time to handoff. The user with the minimum remaining time has the highest priority for reserving a channel in the target cell. As the reserved channel is held only for the user who reserves it, this scheme is not efficient in terms of resource utilization because of the possibility of false reservation due to call terminations or changes in movement direction, as well as reservation failures due to fast user movement or resource unavailability at the reservation-request time. Since resource reservation in [4] and [5] is based on positioning and velocity without consideration of the wireless channel fading, the serving BS may not be the one with the best connection; this circumstance can degrade system capacity in CDMA networks. An adaptive channel reservation scheme is proposed in [3] with a fixed channel reservation-request threshold which takes a value less than that of the target BS add (ADD) threshold. The scheme does not consider any changes in the received pilot signal strength (RPSS), which contains user mobility and fading information. With a high reservation-request threshold, a fast-moving user may encounter handoff failure because of the lack of reserved resources; on the other hand, a low reservation-request threshold may incur a waste of reserved resources when a user is moving slowly. Furthermore, none of the above schemes have considered the effect of traffic load on resource reservation.

In this paper, we propose a measurement-based adaptive channel reservation scheme. A reservation is made when a resource reservation request is triggered through a threshold mechanism based on monitor-

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ing the RPSSs. The RPSS difference between the serving and the target BSs is used to determine whether a resource reservation request and handoff process should be initiated or not. Our use of the RPSS difference rather than the absolute RPSS value from the serving BS is based on the fact that CDMA is interference-limited. An MS should always be connected to the BS with better communication quality even if the RPSS from the serving BS is sufficient for satisfactory communication. To balance the fast-moving-user handoff failure due to a lack of reserved resources and the resource waste due to slow-moving users, a time threshold, which is the time remaining until a handoff is expected to occur, is introduced for administering resource reservation. This change is based on the fact that the duration of the time during which a target BS prepares the requested resources depends solely on the traffic load and service characteristics, not on user mobility. A reservation request for a fast-moving user is triggered by a large RPSS difference, while for a slow-moving user the RPSS difference is much smaller. Therefore, the RPSS difference adapts to varying user mobility so that the amount of reserved resources can be appropriately set aside and efficiently utilized. In addition, the effect of traffic load on the time threshold in resource reservation is also investigated. When the system traffic load is heavy, it is desirable to initiate resource reservation requests early in order for the target cell to have the requested resources ready before a handoff occurs. On the other hand, in a light-traffic situation, the resource reservation requests can be sent to the target BS late to eliminate excessive new call blocking probability. Thus, the reservation-request time threshold can adapt to the traffic load to achieve better grade of service (GoS) performance. The reserved resources for each individual request form a common reservation pool which is used exclusively for handoff calls on a first-come, first-served (FCFS) basis. The common reservation pool for handoff calls can take advantage of multiplexed use of the available reserved resources to decrease the handoff call dropping probability at the system level.

The novelty of the proposed research is the joint consideration of the effect of user mobility and traffic variation on handoff initiation and execution. The remainder of the paper is organized as follows. Section II describes the system model, including CDMA wireless cellular network structure, propagation model and the GoS performance definition. An overview of the soft handoff signalling process and the extra signalling overhead introduced for the proposed adaptive resource reservation scheme is presented in Section III. The proposed adaptive resource reservation scheme is also presented in this section. Simulation results and performance comparisons are given in Section IV, followed by conclusions in Section V.

II. System model

A. System structure

A frequency-division duplex CDMA (FDD/CDMA) network, in which the uplink and downlink use different frequency bands to provide frequency isolation, is shown in Fig. 1. The network structure has two tiers. The first tier is a mesh connection of mobile switching centres (MSCs) which connect the wireless subnetworks with the backbone network. An MSC collects status information from all its serving BSs and performs most of the resource management functions of a CDMA wireless network, including call admission control (CAC), mobility management, radio resource management, and so on. The second tier consists of a cluster of BSs, each connected to a serving MSC. A BS plays two roles. First, it takes part in the radio resource management under the control of the MSC. Second, it works as the interface between an MS and its serving MSC. An MS keeps an active connection with the serving BS by monitoring the RPSS. Each mobile user samples the RPSS values from its serving BS and the neighbouring BSs every Δt s. Without loss of generality, we assume that only two BSs are involved in the handoff. Handoff decisions are made based on three thresholds: the resource reservation-request time ($T_{\rm rev}$) threshold, the target BS add threshold, and the previous BS drop (DROP) threshold. The $T_{\rm rev}$ threshold is selected based on the remaining time

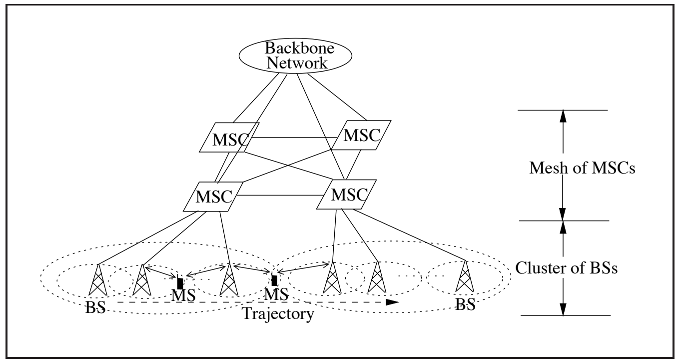

Figure 1: *Network structure.*

until a soft handoff process takes place, while both ADD and DROP thresholds are computed based on the RPSS differences. The ADD and DROP thresholds together define the soft handoff area. Whenever the remaining time reaches $T_{\rm rev}$, or when the ADD or DROP threshold is reached, a message is formed by the MS and sent back either by piggyback or by a specific signalling channel to the serving MSC via the serving BS for decision making. If the target BS is served by a different MSC, the message is further forwarded to the target MSC for a decision. This message includes the target-cell identification and all the other handoff-related parameters. The MSC directs the target BS to reserve resources and the MS to add or drop an active BS. With the deployment of a central data collection and mediation point for the radio access network, the knowledge of traffic load information in the neighbouring BSs makes it possible that thresholds can be adaptively determined to maintain performance requirements. Here, we consider only the adaptation of the $T_{\rm rev}$ threshold to the varying traffic load in performance evaluation.

B. Propagation model

The received downlink pilot signal strength at each mobile station is affected by three components: path loss, which depends on the user location, slow shadowing and fast fading. It is assumed that fast fading can be taken care of by the physical-layer functions, so that the channel is characterized by path loss and shadowing [6]. Denote $p_{k,i}$ as the RPSS signal received at time t_k from the i-th base station. Therefore, the RPSS is formulated in decibels as

$$p_{k,i}(\mathrm{dB}) = p_{0,i} - 10\eta \log_{10} d_{k,i} + \xi_{k,i}, \tag{1}$$

where $p_{0,i}$ is a constant determined by the transmitted power, the wavelength, and the antenna gain of the i-th BS; η is the path loss exponent; $d_{k,i}$ is the distance from the i-th BS to that mobile user; and $\xi_{k,i}$ is the logarithm of the shadowing component, which is a Gaussian-distributed random variable with zero mean and standard deviation σ_i. To capture the large-scale autocorrelation property of shadow fading, a log-normal first-order autoregressive (AR-1) model is applied [7]. Therefore, $\xi_{k,i}$ can be written recursively as

$$\xi_{0,i} = \sigma_i^2 W_{0,i},$$
$$\xi_{k+1,i} = \varrho_{k,i}\xi_{k,i} + \sigma_i\sqrt{1-\varrho_{k,i}^2}\,W_{k,i},$$

where $\varrho_{k,i}$ is the correlation coefficient of $\{\xi_{k,i}\}$,

$$\varrho_{k,i} = \exp\left(-\frac{v_k \Delta t}{\bar{d}_i}\right).$$

$\{W_{k,i}\}$ are independent and identically distributed (i.i.d.) Gaussian random variables with zero mean and unity variance; v_k is the mobile user's velocity, and $\bar{d}_i$ is the shadow fading correlation distance.

C. GoS performance

The GoS parameters under consideration are new call blocking probability P_b and handoff call dropping probability P_d. To achieve maximum revenue for the service provider while at the same time achieving

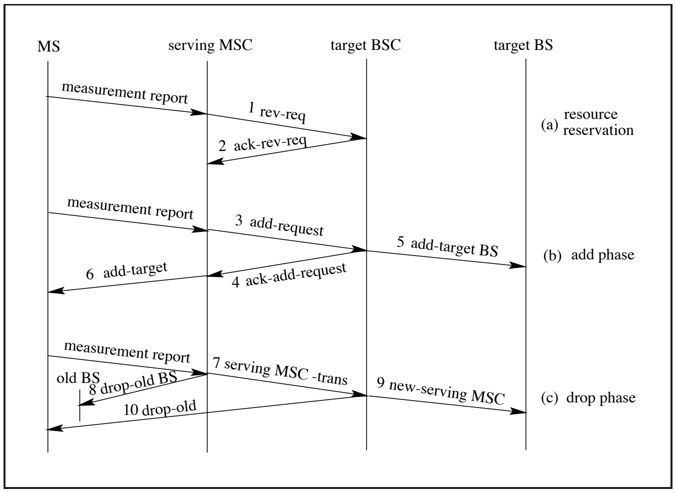

Figure 2: *Soft handoff signalling.*

user satisfaction, the GoS measure is defined as a combination of P_b and P_d:

$$\mathrm{GoS} = P_b + \gamma P_d, \quad (2)$$

where γ is a weighting factor to place greater importance on handoff call dropping probability. For example, $\gamma = 10$ is used in [8]. It is noted that P_b and P_d are a pair of conflicting performance parameters. Insufficient resource reservation will cause high handoff call dropping probability, while excessive resource reservation makes new call blocking probability high. Therefore, the time-varying communication environment makes adaptive resource reservation a desirable choice.

III. Adaptive resource reservation in handoff

Soft handoff takes place when an MS is in the intersection of the coverage area of two or more BSs. In order to guarantee the handoff call dropping probability, some reservation resources are required before handoff. User mobility and traffic load variations cause handoff attempts to change, making a fixed amount of resource reservation inappropriate. A reservation scheme which adapts to variations of handoff attempts is required. In the following, we first give a brief overview of the soft handoff signalling process and its related extra signalling overhead, and then present in detail the proposed adaptive resource reservation scheme.

A. Soft handoff signalling

An MSC is solely responsible for the execution of soft handoff. Intra-MSC handoff is handled by the serving MSC locally without intervention of other system elements. Here we focus on the inter-MSC soft handoff signalling process.

Two phases comprise the inter-MSC soft handoff: add and drop. Figs. 2(b) and 2(c) show the message flows in the add and drop phases. The process for add and drop is shown as pseudocode 1.

Pseudocode 1: Add and drop process in soft handoff

1 Each MS searches and averages the RPSS measurements;

2 RPSS measurements are reported;

3 If (a pilot signal is detected not associated with any forward traffic channel) && (RPSS measurement > ADD threshold)
/* add process */

- **3.1** The serving MSC sends *add-request* message to the new target MSC;
- **3.2** The new MSC performs resource allocation;
- **3.3** If (successful resource allocation)
  - **3.3.1** Acknowledge the serving MSC with *ack-add-request*;
  - **3.3.2** The new MSC sends an *add-target BS* message to the new BS;
  - **3.3.3** The serving MSC directs the MS to add the new BS into its active set with *add-target*;

4 If (a pilot signal is detected with RPSS > DROP threshold)
/* drop process */

- **4.1** The serving MSC sends a *serving MSC-trans* to the new MSC;
- **4.2** The serving MSC asks for dropping of the old BS with message *drop-old BS*;
- **4.3** The new MSC informs the new BS that it will act as a serving MSC with message *new-serving MSC*;
- **4.4** The new MSC sends a *drop-old* message to direct the MS to drop the old BS from its active set.

By introducing an adaptive resource reservation scheme to the system, we will incur some extra signalling overhead. Resources must be reserved before a handoff takes place. The extra signalling is shown in Fig. 2(a), and the process is shown as pseudocode 2.

Pseudocode 2: Resource reservation

1 Each MS searches and averages the RPSS measurements;

2 RPSS measurements report;

3 If (the estimated time interval at which a handoff will occur $< T_{\mathrm{rev}}$)
/* resource reservation */

- **3.1** The serving MSC sends a *rev-req* message to the new target MSC to request resource reservation;
- **3.2** The target MSC performs resource reservation;
- **3.3** The target MSC acknowledges the serving MSC with *ack-rev-req*, indicating reservation success or failure.

A successful reservation can avoid excessive reservation requests from the same MS, while a failed one indicates that a reservation request can still be sent to the target MSC in the next time interval. Based on the signalling process in Fig. 2, the introduced extra signalling load for resource reservation is relatively light.

B. Adaptive resource reservation scheme

In this subsection, we first study the user mobility adaptation, and then the traffic load adaptation for resource reservations.

Each MS samples the RPSS from both the serving and the neighbouring BSs every Δt s. Since an instantaneous sampled RPSS is affected by many factors, such as fading and measurement noise, it cannot exactly reflect the point at which resource reservation should be triggered. Exponential averaging [9] is applied to smooth out the uncertainty due to its simplicity in terms of arithmetic and shortened storage buffer requirement for past information. The exponential-average process is carried out on each successive measurement, so that the smoothed function $S_{k,i}$ of the measurements is

$$S_{k,i} = \beta_{k,i} S_{k-1,i} + (1 - \beta_{k,i}) p_{k,i}, \quad (3)$$

where $\beta_{k,i}$ is a smoothing factor representing the weighting value given to the previously estimated RPSS, which is an important parameter in estimating the present RPSS. With high mobile velocity, the path loss varies significantly, indicating that the previous RPSS should have less effect on the current RPSS estimation. On the other hand, the path loss variations may be negligible with low mobile velocity, indicating a strong correlation between the previous RPSS and the present RPSS values. The shadow fading correlation coefficient $\varrho_{k,i}$

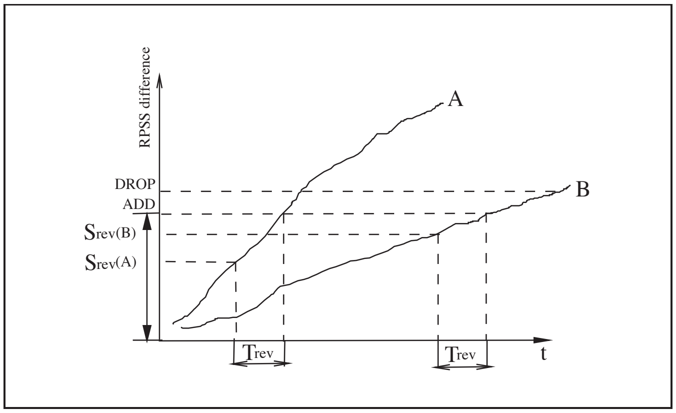

Figure 3: *RPSS difference vs. $T_{\rm rev}$.*

also has an important influence on the smoothing factor $\beta_{k,i}$. With strong correlation effect, the value for $\beta_{k,i}$ should be close to 1, while a weak correlation effect of shadow fading implies a small $\beta_{k,i}$ value. Therefore, $\beta_{k,i}$ implies the correlation between the previous and the present measurements. A consecutive sequence of M recent RPSSs, $p_{k-j,i}, j = 0, 1, \ldots, M-1$, is used to estimate the smoothing factor $\beta_{k,i}$. Let $\bar{p}_{k,i}$ be the mean RPSS over M samples, and let $\bar{\sigma}^2_{k,i}$ and $\mathrm{Cov}_{k,i}$ be the sample variance and covariance, respectively. Then the smoothing factor $\beta_{k,i}$ is estimated as $\beta_{k,i} = \mathrm{Cov}_{k,i}/\bar{\sigma}^2_{k,i}$, where

$$\mathrm{Cov}_{k,i} = \frac{1}{M-1}\sum_{j=0}^{M-2}(p_{k-j,i} - \bar{p}_{k,i})(p_{k-j-1,i} - \bar{p}_{k,i}),$$

$$\bar{\sigma}^2_{k,i} = \frac{1}{M}\sum_{j=0}^{M-1}(p_{k-j,i} - \bar{p}_{k,i})^2,$$

$$\bar{p}_{k,i} = \frac{1}{M}\sum_{j=0}^{M-1} p_{k-j,i}.$$

Apart from the serving BS, the BS with the most significant $S_{k,i}$ is expected to be the target BS that the mobile user is approaching. To make efficient use of radio resources, resources are reserved only when a potential handoff call triggers a resource reservation request in the target BS. Rather than establishing a specific reservation in which a reserved channel can only be used by the user who reserves it, the reserved resources form a common reservation pool for all the incoming handoff calls. A handoff call dropping event occurs when an incoming handoff call cannot find a spare channel. There are two scenarios for handoff dropping. The first occurs when all the reserved resources are used by other handoff calls and the target cell cannot provide the incoming handoff call with the necessary resources. The second occurs when the travelling mobile has already entered the target cell and can no longer communicate with the serving BS, but the target cell does not have spare resources to admit the handoff call. On the other hand, when a user moves slowly and the traffic load is light, there is more chance that the requested resources will be available when a handoff takes place. Thus, a time threshold which reflects dynamic user mobility rather than an RPSS threshold plays an important role in resource reservation and handoff prioritization. Fig. 3 illustrates the proposed reservation-request time threshold with different user mobility. $S_{\rm rev}$ is the difference in RPSS between the smoothed RPSS from the serving BS, $S_{k,i}$, and that from the potential target BS, $S_{k,j}$, where i and j denote the serving and the target BSs when a reservation request is initiated. In the same communication environment, given the reservation-request time threshold $T_{\rm rev}$, the value of $S_{\rm rev}$ varies according to user movement. A user moving quickly away from its serving BS, such as user A in Fig. 3, will initiate a resource reservation request with a much lower $S_{\rm rev}$ value than a slowly moving user (B in Fig. 3) to make the reserved resources available when a handoff is actually requested. Because of the randomness in user mobility and shadow fading effects, the RPSS difference varies nonlinearly with time. Since making reservations too early will waste resources and potentially increase new call blocking, while too late a reservation will cause handoff call dropping, close prediction of the reservation-request time is desired. As a compromise between prediction accuracy and computational complexity, we propose to use the following second-order prediction:

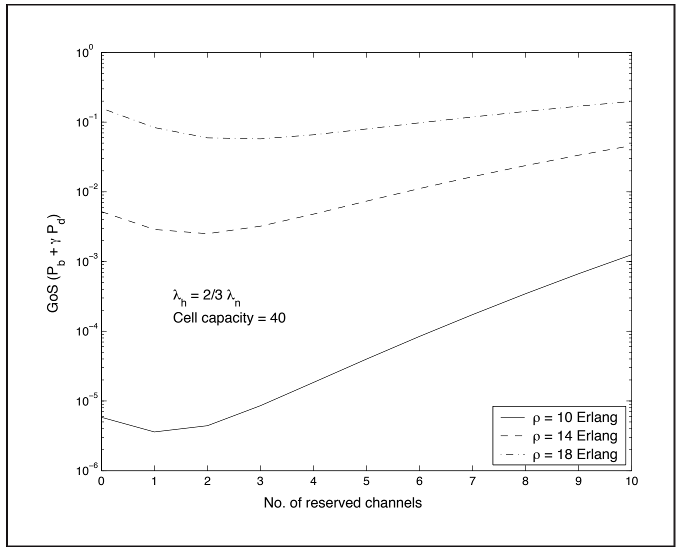

Figure 4: *GoS vs. number of reserved channels.*

$$S_t = S_k + v_{S,k}t + \frac{1}{2}a_{S,k}t^2, \tag{4}$$

where S_t is the ADD threshold beyond which a soft handoff occurs and the MS takes advantage of the better link quality of two simultaneously communicating BSs to maintain minimum interference; S_k is the RPSS difference at time t_k; $v_{S,k} = (S_k - S_{k-1})/\Delta t$ reflects the changes in the RPSS, and $a_{S,k} = (S_k - 2S_{k-1} + S_{k-2})/\Delta t$ captures the variation of the changes in RPSS; t is the expected time interval at which a handoff will occur. Whenever the predicted time interval $t \leq T_{\rm rev}$, a reservation request is triggered. The reserved resources are tagged as a common reservation pool which is exclusively used by handoff calls.

Compared to the fixed channel reservation-request threshold based on RPSS values in [3], the second-order formulation of RPSS difference in the prediction of reservation-request time captures the mobility variations. A common reservation pool eliminates the risk of false reservation since the available reserved channels can be used for fast-moving users that fail to reserve resources before handoff. Also, it can accommodate mobility and fading variations in which the resources reserved early can be used for actual early handoffs rather than for the mobile user who reserves the resources but hands off later due to a speed decrease or change in moving direction. Thus, the pooling mechanism can achieve resource sharing which provides multiplexing gain to the resource utilization.

$T_{\rm rev}$ is the allowed time duration for the target BS to prepare the requested resources before a handoff occurs. It determines the number of reserved channels which accordingly affect the predefined GoS. Fig. 4 shows the relationship between the GoS and the number of reserved channels with traffic load ρ as a parameter. It also shows the relation between the new call arrival rate λ_n and the handoff call arrival rate λ_h. For illustration purposes, we assume that both the new call and the handoff call arrivals follow a Poisson process, and the cell capacity is a constant. When traffic load increases, both new call blocking and handoff call dropping probabilities increase. Because the weighting factor γ in the GoS measure is a penalty factor, the higher the handoff call dropping probability, the greater will be the resulting penalty. Therefore, the number of reserved channels that achieve the minimum GoS increases with traffic load. In Fig. 4, as the traffic load ρ increases from 10 to 18 erlang, the number of reserved channels that

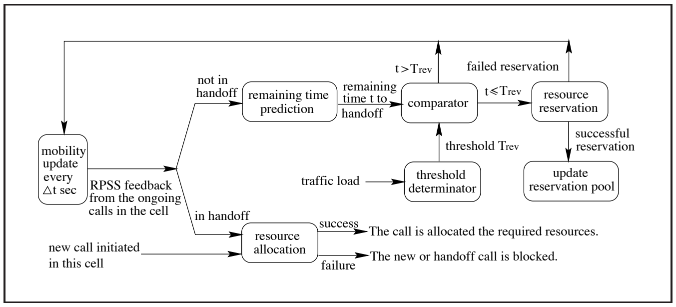

Figure 5: *Simulation flowchart.*

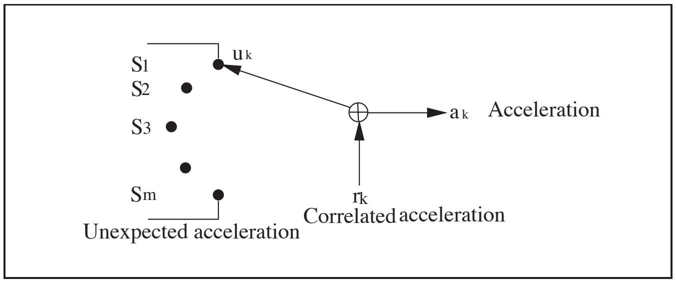

Figure 6: *Acceleration model.*

achieve the minimum GoS increases from 1 to 3. A successful channel reservation is achieved either when there is a spare channel the first time a reservation request is triggered, or when there is a channel release before the handoff occurs. The probability of a successful channel reservation, P_{succ}, is expressed as

$$\begin{aligned} P_{\mathrm{succ}} = {} & P_r\{\text{a spare channel at request}\} \\ & + P_r\{\text{no spare channel at request}\} \\ & \times P_r\{\text{ channel holding time} < T_{\mathrm{rev}}\}. \end{aligned} \tag{5}$$

Intuitively, with the same user mobility, the higher the traffic load in the system, the higher the channel occupancy and the lower the probability of a successful reservation at request time. To compensate for this tendency, a larger T_{rev} is needed to increase the probability of a channel release before a handoff (the second term in (5)). Therefore, it is expected that heavy traffic load will prompt a larger reservation-request time threshold T_{rev}, while light traffic load will lead to smaller T_{rev}.

In summary, the measurement-based adaptive resource reservation scheme applies a user-assisted handoff algorithm. The resource reservation decisions are exclusively based on the RPSS information fed back from each mobile user. There is no fixed number of reserved resources for handoff calls, and each call makes a reservation request before handoff occurs. The reserved resources are pooled for all the incoming handoff calls rather than for a specific user in order to improve resource utilization. This can also reduce signalling cost because it makes cancellation of false reservations unnecessary. By adjusting the reservation-request time threshold with traffic variation, minimal GoS can be achieved.

Based on the above analysis, by introducing the proposed signalling overhead and the remaining-time prediction in the resource reservation phase, the proposed adaptive resource reservation scheme can fit well into current wireless CDMA networks without introducing too much computational complexity.

IV. Simulation results

A. Simulation model

To examine the performance of the proposed adaptive resource reservation scheme, a discrete-event-driven simulation is performed for a conventional hexagonal cellular network with a cluster of seven cells. The cell radius is 300 m, and the relative handoff area occupies 36% of a normal cell area, which represents a reasonable soft handoff region. The path loss exponent η is chosen to be 4, and the standard deviation for shadow fading is 8. The shadow fading correlation distance $\bar{d}_i$ is set to be 20 m for all the cells. Call holding time is assumed to be exponentially distributed with a mean of 120 s. There are two kinds of mobile users: (1) pedestrians who are assumed to have a fixed velocity of 1 m/s with uniformly distributed direction in $[0, 2\pi)$; (2) mobile users in moving vehicles characterized by the mobility model described in the following subsection. For the simulation, we assume that the soft capacity in CDMA systems can be mapped into a capacity of 60 channels in each cell, and that each call occupies one channel when it is on.

The simulation model is shown in Fig. 5. The mobility of each ongoing call in a cell is updated every Δt s according to the mobility model described in the next subsection. New call arrivals follow a Poisson process. Each MS periodically reports its RPSS measurements. When the measured RPSS difference between the serving and the potential target BSs is within the ADD and DROP thresholds, the call is in the soft handoff region. A resource allocation process is triggered if the call just enters the handoff region. When there is no spare resource available, a handoff call dropping event occurs. If the call is not in soft handoff, the remaining time to handoff is predicted and compared to the resource reservation time threshold to determine whether this call needs resource reservation in its potential target cell. The reservation time threshold is adjusted based on the traffic loads among neighbouring cells. Whenever a resource reservation request is formed, the potential target cell performs the resource reservation and updates its reservation pool if the process is successfully implemented.

All the modules in Fig. 5 have been studied except the user mobility update process. In the following subsection, a detailed mobility model which characterizes a practical moving pattern is presented.

B. Mobility model

A mobility model should mimic the behaviour of human movement. We model the user mobility by three parameters: location, velocity and acceleration, on a two-dimensional plane. For velocity and acceleration, a two-dimensional vector determines both the values and directions. The mobile speed varies because of acceleration or deceleration. For description simplicity, we use the term acceleration with both positive and negative values to represent acceleration and deceleration. Therefore, the following model focuses on establishing mobile acceleration. Assume a user's mobility is updated at discrete time instances $t_k = t_0 + k\Delta t$, where t_0 is the initial time epoch, Δt is the sampling interval and k is an integer. In reality, a mobile user may experience unexpected changes in acceleration caused by traffic lights or road conditions; on the other hand, the acceleration is highly correlated, i.e., if a moving user is accelerating at time t_k, it is likely to continue accelerating at time t_{k+1} until it reaches the speed limit. In order to take these two effects into consideration, following [10], we model a user's mobility as a dynamic system driven by an unexpected acceleration $\mathbf{u}_k = [u_{x,k}, u_{y,k}]^T$ and a correlated acceleration $\mathbf{r}_k = [r_{x,k}, r_{y,k}]^T$ at time t_k, as shown in Fig. 6. The variable $\mathbf{u}_k$ is modelled as a Markov process with a finite number of "states," $Q_1, Q_2, \ldots, Q_m$, as possible discrete levels of acceleration. The transition probability $\theta_{i,j} = P\{\mathbf{u}_k = Q_j \mid \mathbf{u}_{k-1} = Q_i\}$ can be approximated by a value ϵ near unity for $i = j$, and $(1-\epsilon)/(m-1)$ for $i \neq j$ [10]. The correlated acceleration can be modelled as a zero mean Gaussian random variable with a variance that is chosen to cover the "gap" between adjacent acceleration states. To represent the correlation feature of $\mathbf{r_k}$, a first-order AR model, $\mathbf{r}_{k+1} = \alpha\mathbf{r}_k + \mathbf{w}_k$, is used, where $\mathbf{w}_k$ is a zero mean white Gaussian vector with variance $\sigma^2_{\mathbf{w}}$ in one dimension.

Denote x_k and y_k as the horizontal and vertical coordinates of a mobile user's random location at time t_k, and $v_{x,k}$ and $v_{y,k}$ as the corresponding velocities. The user mobility vector denoting user location, velocity and acceleration can be expressed as

$$\mathbf{\Psi}_k = [x_k, v_{x,k}, r_{x,k}, y_k, v_{y,k}, r_{y,k}]^T. \tag{6}$$

Combining the driving model in Fig. 6 with the second-order motion model, we can express the discrete-time dynamic equations in the X dimension as

$$\begin{cases} x_{k+1} = x_k + v_{x,k}\Delta t + (r_{x,k} + u_{x,k})\dfrac{\Delta t^2}{2}, \\ v_{x,k+1} = v_{x,k} + (r_{x,k} + u_{x,k})\Delta t, \\ r_{x,k+1} = \alpha r_{x,k} + w_{x,k}. \end{cases} \tag{7}$$

The discrete-time dynamic equation in the Y dimension will have the same expressions as (7), with x replaced by y. Rewriting these equation sets in a more compact matrix form, we have

$$\mathbf{\Psi}_{k+1} = A\mathbf{\Psi}_k + B\mathbf{u}_k + C\mathbf{w}_k, \tag{8}$$

where

$$A = \begin{bmatrix} 1 & \Delta t & \frac{\Delta t^2}{2} & 0 & 0 & 0 \\ 0 & 1 & \Delta t & 0 & 0 & 0 \\ 0 & 0 & \alpha & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & \Delta t & \frac{\Delta t^2}{2} \\ 0 & 0 & 0 & 0 & 1 & \Delta t \\ 0 & 0 & 0 & 0 & 0 & \alpha \end{bmatrix},$$

$$B = \begin{bmatrix} \frac{\Delta t^2}{2} & 0 \\ \Delta t & 0 \\ 0 & 0 \\ 0 & \frac{\Delta t^2}{2} \\ 0 & \Delta t \\ 0 & 0 \end{bmatrix}, \quad C = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}.$$

Five levels, $(-4, -2, 0, 2, 4)$ m/s^2, are selected as unexpected accelerations. The probability, ϵ, of having the same unexpected acceleration in the next time interval is 0.9, so that the probability of changing to any one of the other levels is 0.025. The correlation coefficient of the correlated acceleration α is chosen to be 0.6, and the variance of $\mathbf{w}$ is set to be 0.72. The speed limit is set to be 17 m/s, which is reasonable in an urban area. Considering the computational complexity, the practical service continuity requirements and the fading property, we choose $\Delta t = 1$ s for the mobility update and RPSS averaging [11].

C. Performance evaluation

To evaluate the performance of the proposed scheme, we make comparisons with two other schemes: (a) specific channel reservation based on RPSS values [3], and (b) specific channel reservation based on the remaining time to handoff [5]. In specific channel reservation, the reserved resources are set aside only for the user who reserves them. Therefore, reservation cancellation is required to release falsely reserved channels due either to termination of the potential handoff call before handoff, or to a turn in another direction. In (a), if the RPSS drops below the reservation threshold for a predefined period, the MS requires the associated BS to release the reserved capacity. In (b), whenever the expected remaining time to handoff elapses, the reserved resources are released to avoid false reservation. On the other hand, there is no reservation cancellation for the proposed scheme. In addition, there is no reservation checkup at the time a user moves out of the handoff region as in [3] because in a reasonable mobility pattern, it is assumed that there are no abrupt acceleration changes. Therefore, the proposed reservation scheme based on the remaining time to handoff performs better than that based on RPSS values, since the probability of false reservation is reduced. We denote schemes (a) and (b) and the proposed schemes as spec_RPSS, spec_time, and comm_time, respectively. Table 1 tabulates the achieved minimum GoS performance with the new call arrival rate being 0.35 users/s and the ratio of pedestrian users to vehicle users (denoted as mobility in the table) being 0.8, 0.7, and 0.6.

It can be seen from Table 1 that the proposed scheme outperforms the other two schemes in that the GoS performance is improved significantly with the same communication environments and traffic loads.

Table 1
GoS performance (new call arrival rate = 0.35 users/s)

Mobility	0.8	0.7	0.6
spec_RPSS	0.1240	0.1143	0.0815
spec_time	0.1113	0.0981	0.0782
comm_time	0.0785	0.0742	0.0692
Improvement over spec_RPSS	36.7%	35.1%	15.1%
Improvement over spec_time	29.5%	24.4%	11.5%

As the ratio of pedestrian users to vehicle users decreases, the GoS performance improves gradually for all three schemes because the high channel occupancy and release rates result in efficient resource utilization. The proposed adaptive resource reservation scheme is also an efficient approach to prioritize handoff calls while at the same time keeping the new call blocking probability low.

Fig. 7 shows the GoS performance versus reservation-request time thresholds. The new call arrival rate is set to be 0.35 users/s. It can be seen that, with small thresholds, the GoS degrades due to the high handoff call dropping probability caused by insufficient resource reservation. As the reservation-request time threshold increases, the GoS degrades as well due to the high new call blocking probability caused by excessive resource reservation. As the ratio of pedestrian users to vehicle users increases, the reservation-request time threshold that achieves minimum GoS performance increases from 6 to 9 s. This result is due to the fact that calls with higher mobility increase multiplexing gain in resource utilization. The increasing reservation-request time threshold causes inefficient utilization of the reserved resources, especially in low-mobility environments.

Capacity utilization versus reservation-request time thresholds is shown in Fig. 8. When the reservation-request time threshold is low, the capacity is efficiently utilized in a low-mobility environment due to the low handoff rate and, accordingly, the low proportion of reserved resources. As the time threshold increases, more resources are reserved for potential handoff calls, which makes capacity utilization inefficient. The low-mobility environment suffers even worse capacity-utilization degradation than the high-mobility environment because a call with a slow-moving user has more chance of terminating before handoff, prompting excessive resource reservation even though those reserved channels can be used by other handoff calls.

The effect of traffic load on reservation-request time threshold, GoS performance and capacity utilization are demonstrated as follows. Fig. 9 shows the GoS versus reservation-request time thresholds with new call arrival rates of 0.3, 0.35 and 0.4. The ratio of pedestrian users to vehicle users is set to be 0.7. It is observed that as the traffic load increases, in order to achieve minimum GoS performance, the reservation-request time threshold increases from 3 s to 12 s, as expected, to balance the weighted handoff call dropping probability and the new call blocking probability. By means of traffic load exchanges among MSCs, each MSC can determine the reservation-request time threshold required to achieve minimum GoS. The capacity utilization versus reservation-request time thresholds is shown in Fig. 10. The increasing thresholds cause excessive reservation, which greatly degrades the capacity utilization.

V. Conclusions

A measurement-based adaptive resource reservation scheme has been proposed for wireless CDMA cellular networks. Simulation results have shown that the proposed resource reservation scheme achieves better GoS performance than specific channel reservation schemes based either on RPSS or on the remaining time to handoff in a cell.

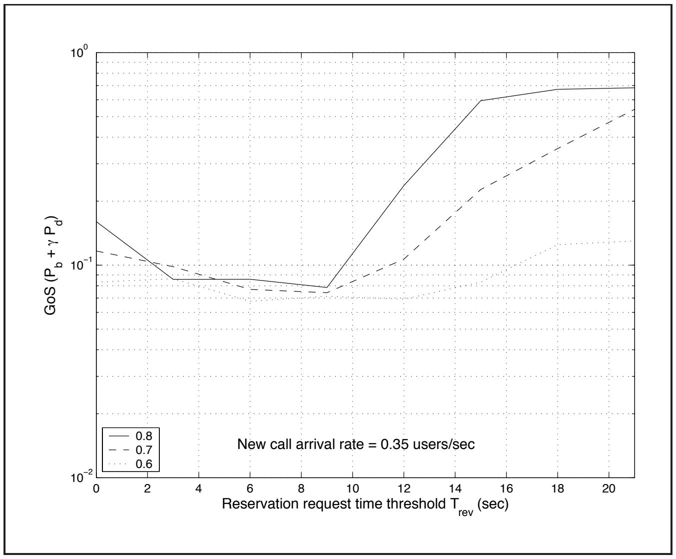

Figure 7: *GoS performance vs. reservation-request time thresholds with the ratio of pedestrian to vehicle users being* 0.8, 0.7 *and* 0.6.

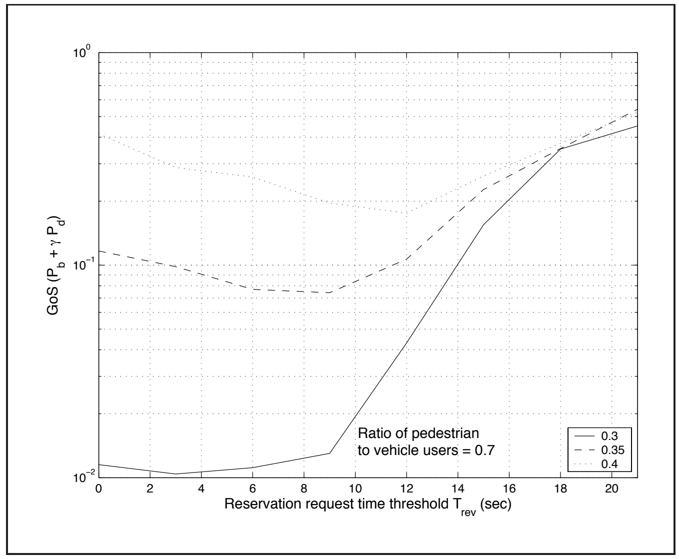

Figure 9: *GoS performance vs. reservation-request time thresholds with the new call arrival rate being* 0.3, 0.35 *and* 0.4.

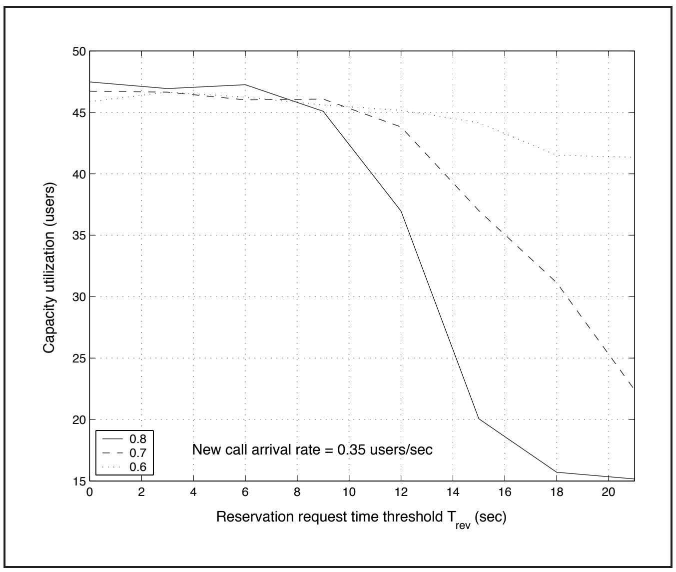

Figure 8: *Capacity utilization vs. reservation-request time thresholds with the ratio of pedestrian to vehicle users being* 0.8, 0.7 *and* 0.6.

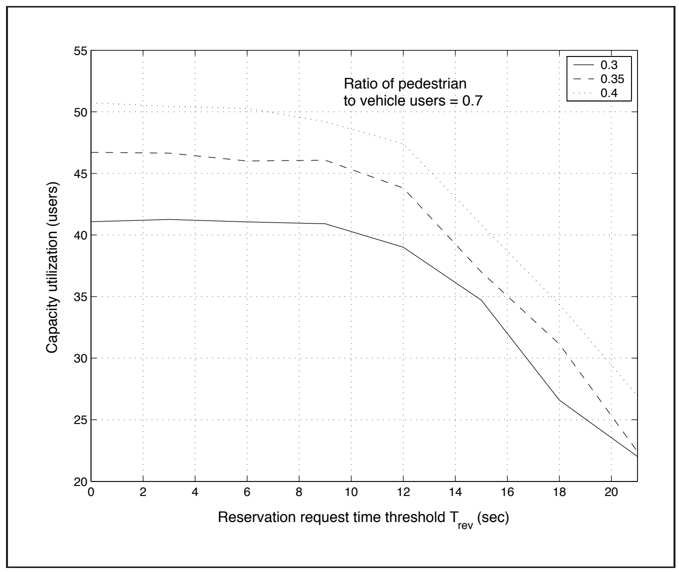

Figure 10: *Capacity utilization vs. reservation-request time thresholds with the new call arrival rate being* 0.3, 0.35 *and* 0.4.

Further research on the impact of CDMA soft capacity on the adaptive resource reservation scheme for multimedia traffic is underway.

Acknowledgements

This work has been supported by a grant from the Canadian Institute for Telecommunications Research (CITR) under the Networks of Centres of Excellence (NCE) program of the Government of Canada.

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