PREDICTIVE HANDOFF SCHEME WITH CHANNEL BORROWING BASED ON THE POSITIONING OF MOBILE STATIONS

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Abstract - Previously, we presented a predictive channel reservation (PCR) scheme for handoff motivated by the rapidly evolving technology of mobile positioning. In this paper, we investigate a new scheme, called PCR_CB, which is an extension of the PCR scheme by allowing channel borrowing from the neighboring cells. In PCR_CB, channel borrowing is invoked when the cell receiving reservation request cannot find any free channel. This is to take advantage of the situation that neighboring cells may have some idle channels at that moment. However, to avoid the negative impact of further depleting the channels of busy cells, the ratio of available channels to total number of channels (coldness index) is checked first on the potential lender cells. This implies the PCR_CB scheme predicts incoming traffic to each cell based on the extrapolated motion path of every single mobile station, and then re-allocate channels according to the traffic trends. Performance evaluation of the PCR_CB scheme is done by simulation. The result shows that PCR_CB outperforms the original PCR and GC schemes by a large margin on handoff blocking while new call blocking is virtually the same as PCR. Non-homogenous traffics, in which some hot cells may exist persistently, are also included in this study. Similar trend is observed as that of homogeneous traffic, although during high degree of non-homogeneity the reduction on the performance gain of PCR_CB can be clearly observed. PCR_CB is also shown to outperform the Channel Carrying scheme on the basis of performance optimization.

Keywords: Channel allocation, handoff blocking, handoff prioritization, mobile positioning, channel borrowing, simulation of cellular networks.

1. INTRODUCTION

Handoff in cellular networks is the mechanism that transfers an ongoing call from the current cell to the next cell as the mobile station (MS) moves through the coverage area of the cellular system. A successful handoff provides continuation of the call which is vital for the perceived *quality of service* (QoS). In case the next cell does not have a radio channel available for the incoming MS, handoff blocking occurs and the call is dropped Note that the term “channel” in the handoff literature has been abstractly used to represent a frequency band for the FDMA access method, a time slot for TDMA and a code-word for CDMA. The lack of channel resources also results in the blocking of new calls.

One of the universally accepted design concepts in cellular networks is that blocking of handoff requests is less desirable than the blocking of new calls. Consequently, several schemes have been proposed to prioritize handoff requests in the literature. The conventional approach to prioritize handoff requests is to specify a threshold on the radio channels within each cell. When the channel occupancy is below this threshold, both new calls and handoff calls are accepted. If the channel occupancy reaches or exceeds the threshold, any incoming new call is blocked and only handoff requests are accepted. The channels reserved for handoffs as a result of this threshold are called *guard channels* (GC) [5,7,17]. GC-based schemes improve the blocking rate of handoff operation but adversely decrease the total traffic of the cellular network due to the increase in the rate of new call blocking. Careful selection of the GC threshold is essential in achieving optimal performance [13,14].

The allocation of channels to a cell can be fixed, flexible, and dynamic [16]. In any case, the co-channel interference must be avoided. Previously, we proposed the Predictive Channel Reservation (PCR) scheme [1], which adheres to simple fixed assignment strategy. In this paper, we investigate a new scheme, called PCR_CB, which is an integration of PCR and the channel borrowing strategy. To avoid co-channel interference, channel locking must be applied to the co-channel cells of the lender cell that provides borrowed channels. Both PCR and PCR_CB schemes attempt to pre-allocate a radio channel in the new cell for each moving MS (mobile station) shortly before the handoff takes place by extrapolating the path of the MS. This scheme is motivated by the real-time position measurement, which is becoming one of the important features of the 3G mobile communication systems. In addition, it takes load balancing into consideration by incorporating the channel borrowing strategy.

The remainder of this paper is organized as follows. In section 2, we discuss previous results on related work in cellular networks and briefly examine the evolving technology of mobile positioning. Section 3 briefly reviews the original PCR scheme and introduces the basic concept and the design consideration of the PCR_CB scheme. The simulation model and performance results are presented in section 4. Section 5 concludes the paper.

2. RELATED WORK

In this section, we first survey some predictive-based schemes, and then briefly describe the Channel Carrying (a variant of channel borrowing) scheme [11] and the LBSB (load balancing with selective borrowing) scheme [3]. We then discuss the recent development in mobile station positioning.

2.1. Predictive-Based Schemes

A predictive-based scheme uses either probabilistic or deterministic methods to estimate the mobility of the mobile stations (MS). The estimation is subsequently used to either make reservation for handoff or perform call admission control. The shadow cluster concept was proposed in [10] to estimate future resource requirements and perform admission control in order to limit the handoff dropping probability. The influence of the active MS on each cell in the cluster is probabilistically determined by the base station based on previous knowledge of the mobility pattern of the MS. However, the method of acquiring this knowledge is not specified in their scheme. Due to the complexity in calculating the influence on each cell in a cluster, the scheme is considered too costly in computation. Lu and Bharghavan [12] explored mobility estimation for an indoor wireless system based on both mobile-specific and cell-specific observation histories. The predictive and adaptive schemes proposed in [2] make bandwidth reservation for handoffs of the existing calls and admission control for new calls. The aggregate history of mobility observed at the cell level is used to predict probabilistically the directions of the MSs and the time of the expected handoff.

In general, the problem with the history-based schemes is two-fold. First, there is always an overhead required to develop, store and manage traffic histories. In addition, these histories can never be fully reliable as they continually go through either short-term (e.g. diversion of traffic due to accident) or long-term (e.g. opening a new shopping center) changes. In our PCR approach the prediction of the future path of an MS is obtained by the use of real-time position measurement which is becoming a standard feature of the mobile devices. The utilization of real-time measurement introduces a set of considerations not addressed in history-based schemes. We will examine these considerations in Section 3.

2.2. Channel Carrying

Channel carrying (CC) scheme was introduced by Li et al. in [11]. This scheme allows an MS to carry its current channel from one cell to another when it moves across the boundary under certain condition. Consider a linear cellular system model with minimum reuse distance r. The minimum reuse distance requirement may be violated when a channel is allowed to be carried into another cell. Since CC is not a reservation scheme, channel locking cannot be applied. Hence, the CC scheme must provide some channel allocation strategy to avoid co-channel interference. An innovative solution is proposed by Li et al., in which the distance of identical set of channels is increased to r+1 instead of r. This prevents co-channel interference when a channel is carried to its neighboring cell. The price to pay is that the number of channels contained in each cell is now reduced by the amount of $\frac{N}{r(r+1)}$, where N is the total number of channels available in the cellular system. Apparently, the smaller the reuse distance, the more the amount of channels is to be sacrificed. In this scheme, the mobility of channels relies completely on localized information, therefore no global coordination is needed. Handoff call requests are greatly favored over new call requests. Compared to Guard Channel scheme, the handoff blocking is significantly improved. However, CC scheme is not suitable in 2-D (metropolitan) environment due to the unacceptable amount of channels wasted when r+1 scheme is applied to the compact patterns and the significantly reduced number of channels that can be carried to each neighbor. In Section 4, the performance of the linear CC scheme will be compared to our PCR_CB scheme on the basis of performance optimization.

2.3. Load Balancing with Selective Borrowing

This is a dynamic channel allocation strategy for load balancing, which allows the migration of unused channels from ‘cold’ cells to a ‘hot’ cell within the compact pattern not just between the neighboring cells [3]. A cell is classified as ‘hot’ if the degree of coldness of a cell (defined as the ratio of the number of available channels to the total number of channels in that cell) is less than some threshold value. Otherwise, the cell is ‘cold’. The algorithm proposed by Das et al. is called load balancing with selective borrowing (LBSB), which is centralized in nature. The users in a cell are divided into three groups with different priority of channel requests. Allocations of the local and borrowed channels are performed differently according to the priority classes. The algorithm can be triggered by a cell whenever it becomes hot or run periodically in the server residing in the MSC.

The LBSB scheme consists of two parts: channel borrowing and channel assignment. In channel borrowing, channels can only be borrowed from the cold cells to the hot cells by using a selection function considering the following factors: coldness of the lender cell, the cell distance between the borrower and the lender cells, and the number of hot co-channel cells of the lender cell. To avoid channel interference with the borrower, the borrowed channel has to be locked in the co-channel cells of the lender. In channel assignment, the available channels (including local and borrowed) are allocated to the users by using some channel allocation strategy to maximize resource. The departing users from a hot cell have the highest priority of using the borrowed channels. Under suitable conditions, intra-cell handoffs are needed to reallocate borrowed channels to departing users and return the local channels that they were using to the available channel set.

The simulation results in [3] clearly shows that the LBSB scheme outperforms the directed retry [9] and the CBWL scheme [8]. In this paper, we investigate the new scheme, called PCR_CB, which is the integration of the PCR scheme and the LBSB scheme with some modifications.

2.3. Mobile Station Positioning

E-911 ruling issued by FCC (Federal Communications Commission) mandates that, by the year 2001 (the deadline has been postponed), the operators of mobile communications networks must be able to accurately locate mobile caller requesting emergency services via 911 [4]. The ruling plays a vital role in recent advancements in the position measurement of mobile devices, which has become one of the important features of the 3G mobile communication systems.

Zhao discussed the location technologies specified by the 3G Generation Partnership Project (3GPP) and 3GPP2, respectively, in his recent article [18]. Various wireless systems are covered by these specifications: Wideband code-division multiple access (W-CDMA) and Global System for Mobile Communications (GSM) systems are covered by 3GPP while cdma2000 and cdmaOne systems are covered by 3GPP2 [15]. Three likely solutions for location measurement are specified in 3GPP, namely, Cell-Id based positioning method, OTDOA positioning method, and Assisted GPS positioning method. Cell-Id based method determined the position of a UE (user equipment) based on the coverage information of its serving cell. OTDOA operates by applying the principle similar to that of GPS, except the satellites are replaced by base stations. Hence, no GPS receivers are required. Both OTDOA and A-GPS provide UE-based (position calculated at the handset) and UE-assisted (position calculated at the network) solutions. UE-based solution is more decentralized than UE-assisted solution, has better scalability, but requires some highly functional unit on the UE. In general, among the three methods specified, the cell-ID-based method has the worst positional accuracy, while A-GPS has the best accuracy. GPS has been widely used in Intelligent Transport Systems. The accuracy achieved by GPS using basic point positioning technique is 100 meters at the 95% probability level. If DGPS (Differential GPS) is employed, accuracy at the 3-5 meters level can be achieved [6]. With the removal of SA (selective Availability) in the GPS measurement, the accuracy of the basic positioning is now within 20 meters. For TDOA based methods, the accuracy of under 100 meters at the 67% level may be achieved. The E-911 accuracy requirement is easily satisfied by using A-GPS method. However, adding a GPS capability to mobile phones may not be a universal solution, since the network operators would be facing the huge task of replacing or retrofitting every piece of mobile phones. To cope with this problem in the short run, OTDOA method, which does not require replacement of hardware, may be an alternative for legacy phones.

3. DESCRIPTION OF THE SCHEME

The basic idea of Predictive Channel Reservation (PCR) is rather simple. Each mobile station periodically measures its current position and reports this information to the base station. Based on the position information, the base station extrapolates the path of the mobile to determine the neighboring cell that the mobile is currently heading to. We may use either OTDOA or A-GPS positioning method described in the previous section. To alleviate the burden of the network, the UE-based solution is preferred. When the mobile is within a certain distance from a neighboring cell, the current base station issues a reservation request to the new base station to pre-allocate a channel for the expected handoff. Cancellation of reservation is also sent if the mobile changes its direction and moves away from the neighboring cell. We have first implemented and tested a simple predictive channel reservation (PCR1) scheme. A high level description of various procedures in this scheme is as follows.

Handoff

```
If  (handoff call has a prior reservation)
        {allocate the reserved channel}
elseif  (there is a free channel)
        {allocate the free channel}
else    {drop call}  // handoff blocking
```

New Call

```
If (there is a free channel)
      {allocate channel}
else  {decline call}   // new call blocking
```

Reservation

```
If (there is a free channel)
{reserve the channel}
else    {ignore request}
```

Cancellation

```
{de-allocate a reserved channel}
```

In section 3.1, a brief review of PCR scheme, published previously by the authors [1], is provided. This is essential in understanding the concept and the design of the new extended scheme, PCR_CB, introduced in section 3.2.

3.1 PCR without Channel Borrowing

It is important to notice that the performance of the predictive schemes based on real-time positioning may be adversely affected by the following factors.

(1) False reservations due to call termination or direction changing of MS that result in cancellation of reservations.
(2) The channel resources may be unnecessarily wasted when reservations are submitted too early.
(3) Reservations submitted at time of congestion are ignored and do not achieve their intended goal of handoff prioritization.

Based on the result of simulations [1], the PCR1 scheme was found to give little improvement over the non-predictive scheme (Guard Channel based), which confirms the above concern. We have proposed a number of strategies aiming to improve or enhance the performance of the basic scheme by rectifying the above factors. These include

Reservation Pooling

Rather than strictly mapping each reserved channel to the mobile that made the reservation, the set of reserved channels at any moment is used as a generic pool to serve handoff requests. Such that incoming handoff requests that did not make prior reservation may still use one of the reserved channels. By the degree of sharing, two schemes, PCR2 (partially shared) and PCR3 (totally shared), are added.

Careful Selection of the Threshold Distance

The concept of Threshold Distance (TD) is used to reduce the likelihood of false reservation. TD, being a distance smaller than the radius of the cell, specifies an inner circle co-centered with the cell. Reservation requests can only be sent when Ms is located outside of the TD. This purpose of TD is to counter the adverse effect of factor (1) and factor (2). The value of TD needs to be carefully selected: larger values of TD reduce the number of false reservations and smaller values of TD improve the chances that a channel will be secured for each handoff.

Incorporating Guard Channels

The pure PCR scheme generates a pool of reserved channels whose size expands and shrinks (dynamic) based on the mobility dynamics in the neighboring cells. Integrating a number of guard channels (static) into the predictive scheme produces a highly improved scheme without introducing excessive bias against new calls. The integrated scheme is called hybrid predictive channel reservation scheme (HPCR1, HPCR2 and HPCR3). The guard channel(s) used to augment the PCR scheme ensures that the handoff requests will still get a priority service even when the reservation mechanism is hampered by a prior congested condition This provision can be considered as a counter measure to adverse factor (3).

Queuing of Reservation Requests

So far, we haven’t modified the reservation procedure of the basic PCR scheme in which the base station ignores reservation requests at time of congestion. To further alleviate the effect of factor (3), these requests are queued up waiting for channels to become free. When the reservation queue is not empty, the channel released by a terminating call is added to the reservation pool and one reservation request is dequeued. Otherwise (i.e., when the reservation queue is empty), the released channel becomes free and can be used by new calls. The queueing mechanism for reservation requests ensures that a majority of the non-false reservation requests will be eventually granted. The schemes after above sequence of improvements are denoted by HPCRQ1, HPCRQ2 and HPCRQ3.

Extensive simulation results have clearly demonstrated that the predictive scheme significantly improves the handoff blocking rate, when compared to GC based scheme, with relatively minor degradation in the admission rate of new calls. Interested reader may refer to [1] for more detail.

3.2 PCR with Channel Borrowing

In this paper, we investigate an enhanced PCR scheme, called PCR_CB that integrates PCR scheme and the channel borrowing strategy. Channel borrowing from the neighboring cells is invoked when the cell that receives the reservation request cannot find any channel available. It takes advantage of the situation that neighboring cells may have some idle channels at that moment. Hence, PCR_CB has the effect of load balancing. However, to avoid the negative impact of depleting the channels from the busy neighboring cell, the lender cell must be carefully selected. Below are the protocols for handling various events that may involve borrowed channel.

Reservation

```
if (there is a free channel)
        {reserve the channel}
else
        {select a neighboring cell X using the selection function
        if (cell X exists)
            {borrow a channel from cell X
            lock channels in co-channel cells
            reserve the channel}
        else {ignore the request}
        }
```

Handoff

Same as that for PCR1, PCR2, orPCR3 except that borrowed channel is always allocated first if there is any.

Cancellation

```
if (there is a borrowed channel reserved)
    {return the channel
    unlock channels in co-channel cells}
else if (there is a reserved channel)
    {de-allocate the channel}
```

Call Termination

```
if (borrowed channel is used)
    (return the channel
    unlock channels in co-channel cells}
else {free the channel}
```

Some features relevant to the implementation of PCR_CB are as follows.

(1). The selection function for channel borrowing in the event of reservation is similar to that of LBSB described in section 3.2. However, for simplicity, we only consider the coldness factor of the lender (the lender must be a 'cold' cell) and the channel migration can only occur between neighboring cells. Recall that coldness is defined as the ratio of the number of available channels to the total number of channels in a cell.

(2). The channel borrowing process is activated the moment when a handoff reservation request arrives to a cell and there is no free channel at that cell. This implies the PCR_CB schemes predict incoming traffic to each cell based on the extrapolated motion path of every single mobile station, and then re-allocate channels according to the traffic trends. Thus with this predictive load balancing, the channel resources are utilized more efficiently.

(3). Enhancements to PCR scheme also apply to PCR_CB. These include reservation pooling, careful selection of TD, and incorporating guard channels. Since channel borrow strategy is incorporated into PCR_CB, the provision of queueing of the reservation requests is simply redundant. Consequently, the group of PCR_CB schemes include HPCR1_CB, HPCR2_CB and HPCR3_CB.

(4). The borrowed channels are always allocated first to the incoming handoffs. So that they can be returned to the lenders and the channels in the co-channel cells can be unlocked as soon as possible.

4. SIMULATION

In this section, we first describe the simulation model of PCR_CB scheme, followed by the presentation of simulation results.

4.1 Simulation Model

In the simulation study of the PCR scheme, we used a model that adheres to the general assumptions made in the literature. Below, we describe the various components of our simulation model and the assumptions for these components.

Cell Model

In our simulation, we use linear cellular system model (1-D) instead of 2-D compact pattern model. In most cases, our simulation tests use a 35x1 cellular patch, a cell radius of 1000m, a minimum reuse distance of 3, and a TD equal to 0.66 of the cell radius. MSs are allowed to wrap around to the other side of the system when moves out of system boundary. Such an arrangement has been used in the simulation study reported in [2,8,11]. It eliminates the burden of handling out of bound situations and is considered an efficient way to approximate the simulation of a very large cellular system. As shown in figure 1, an MS can only move along x-axis.

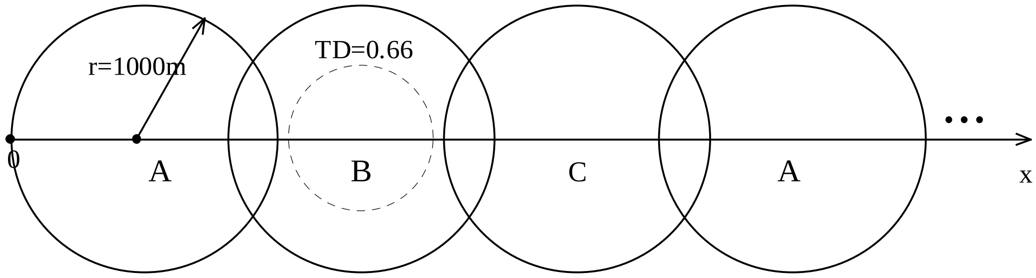

Figure 1: 1-D cellular model

1-D model simplifies the effort of simulation a great deal. It mimics the system on a highway. However, it's not a realistic model for the system on a metropolitan area. The performance evaluation of the PCR_CB scheme in this paper was conducted assuming the highway scenario. The other reason for using 1-D model is that our PCR_CB scheme is to be compared with Channel Carrying (CC) scheme [11], which was proposed as a linear scheme. As indicated earlier, the CC scheme may not be suitable in 2-D scenario.

Traffic Model

We use exponential distribution to determine the duration of each generated call with a mean of 180s. New calls arrive according to a Poisson process and both homogeneous and non-homogeneous traffics among all cells are considered. Each cell is assigned 18 channels unless otherwise stated. The traffic load to each cell is defined as

$$\frac{ArrivalRateToTheCell * AverageCallDuration}{NumberOfChannelsPerCell} * 100\%$$

Mobility Model

In our model, each MS is assigned a initial speed and direction with a average speed of 18meter/s and a maximum speed of 24meter/s (54mph). After a specified time period, which is generated randomly, the speed and direction of the MS are updated. The direction of the motion after this period may preserve the previous heading or may change to the opposite direction.

Another parameter important to the simulation is the interval between two consecutive position measurements. The information is sent from an MS to the base station (BS) through an up-link message assuming that the UE-based method is utilized. The interval is constant and the value is set to 3 seconds. In the remainder of this section, the performance of the proposed new scheme is evaluated via simulation.

4.2 Simulation Results

Extensive simulations are conducted to evaluate the performance of PCR_CB scheme, including homogenous and non-homogeneous traffics. In the following, we present the results based on the simulation model described in Section 4.1 Below is the list of parameters that were fixed during the simulations.

Number of cells: 35
Number of channels per cell: 18
Mean call duration: 180 sec.
Average speed of an Ms: 18 m/s
Position measurement interval: 3 sec.
Threshold Distance: 0.66
Minimum reuse distance: 3
Simulation time: 1,000,000 sec.

We first compare the performances of the three hybrid PC schemes (HPCR1, HPCR2 and HPCR3) and the conventional GC based scheme. Test results on handoff blocking (figure 2) show that HPCR schemes surpass GC scheme except for HPCR1 when the number of reserved channels is low. Figure 3 shows minor degradation of the three HPCR schemes on the new calls blocking.

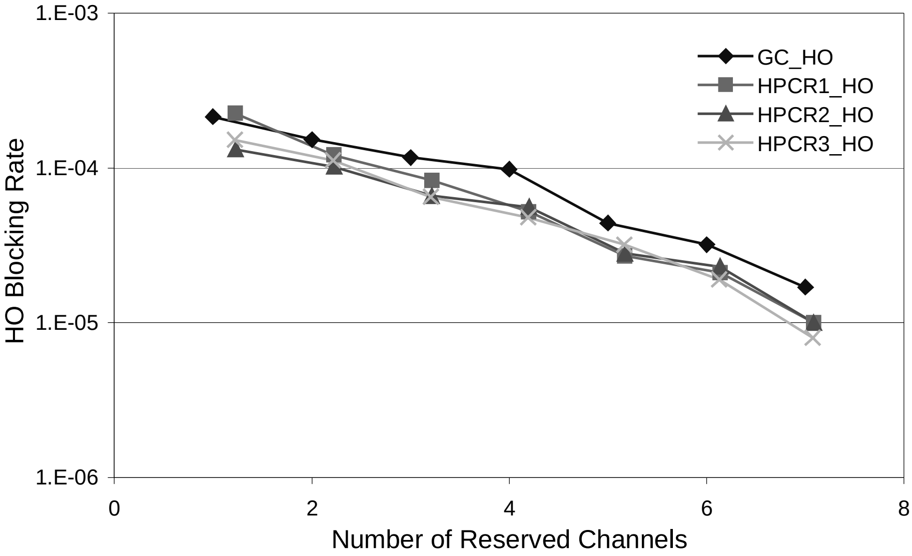

Figure 2: HO blocking rates for HPCR and GC schemes at 40% traffic load

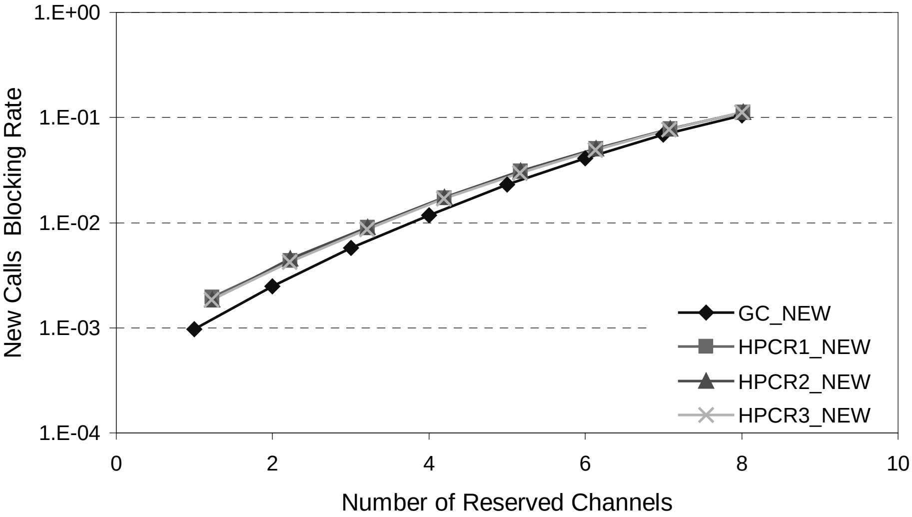

Figure 3: New blocking rates for HPCR and GC schemes at 40% traffic load

Figure 4 and Figure 5 depict the result after comparing HPCR_CB, HPCR and GC schemes at 60% traffic load. It is obviously that PCR schemes improve enormously by incorporating channel borrowing strategy. The three HPCR schemes only show little improvement over GC at this relatively high traffic load. The HPCR_CB group, on the other hand, shows improvement of multiple orders of magnitude over GC and HPCR group. Meanwhile, the new calls blocking rates of all those tested schemes are very close, especially when the number of reserved channels increases.

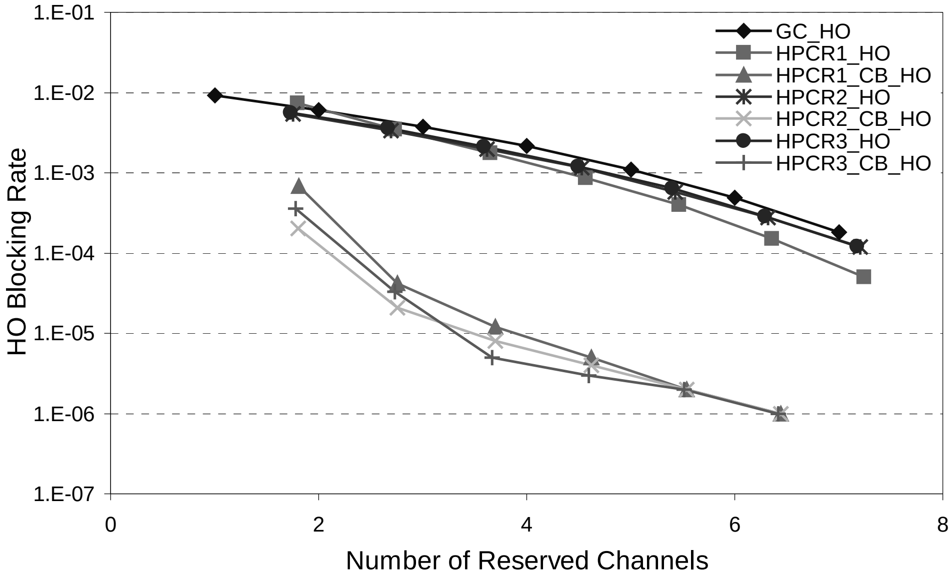

Figure 4: HO blocking rates for HPCR_CB, HPCR and GC schemes at 60% traffic load

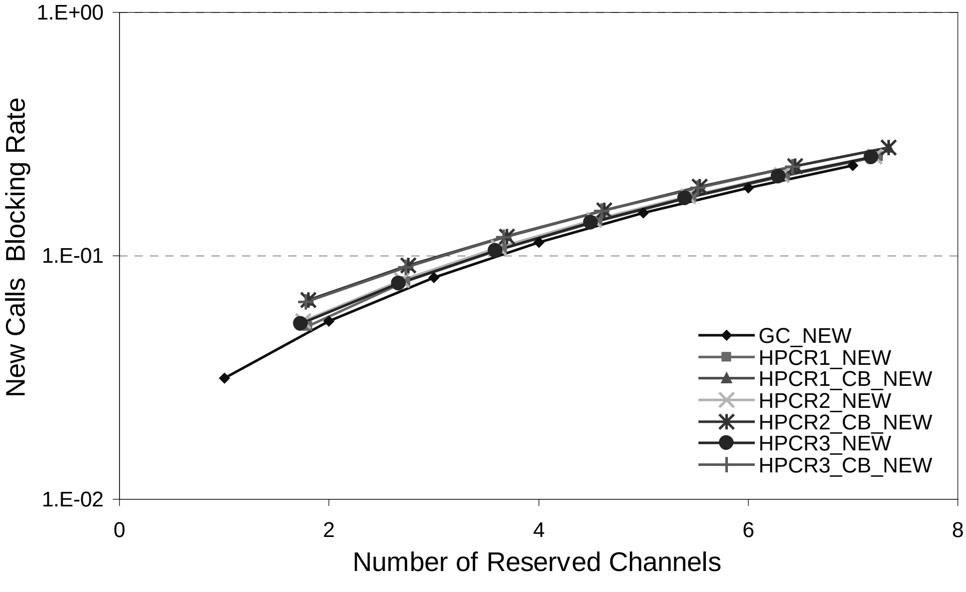

Figure 5: New call blocking rates for HPCR_CB, HPCR and GC schemes at 60% traffic load

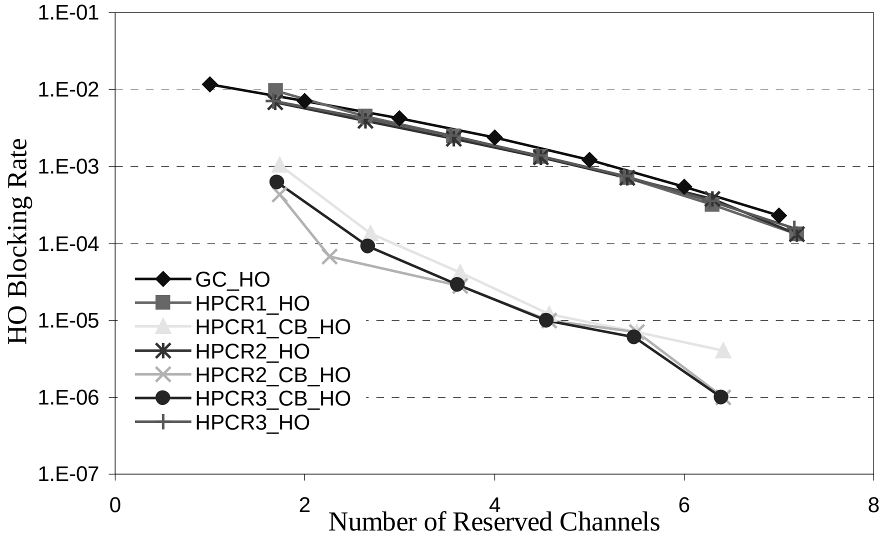

Figure 6: HO blocking rates for HPCR_CB, HPCR and GC schemes at 60% traffic load. Non-homogeneous with 10% new calls in one cell.

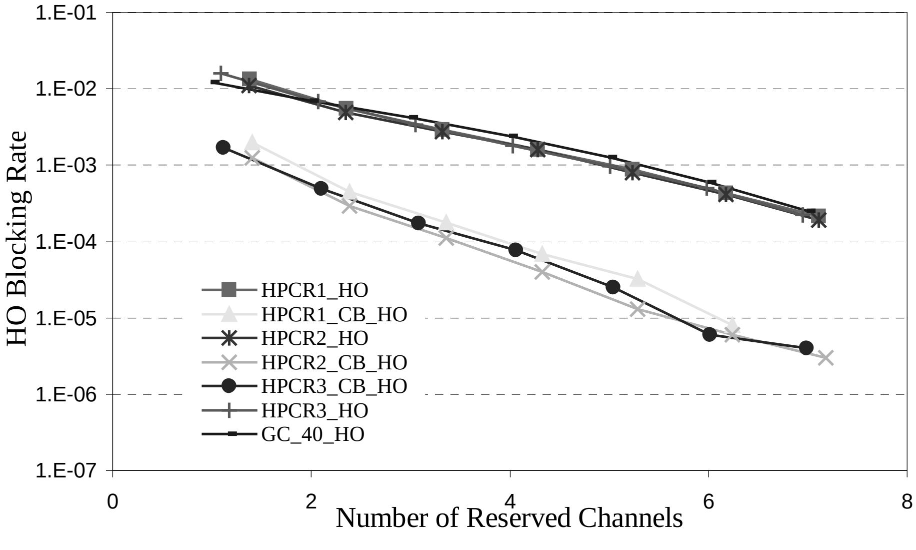

Figure 7: HO blocking rates for HPCR_CB, HPCR and GC schemes at 60% traffic load. Non-homogeneous with 50% new calls in one cell.

Below, we also include the results under non-homogeneous traffic condition when the new calls generated are concentrated at one cell. Figure 6 depicts the result with minor degree of non-homogeneity in which 10% of all new traffic is generated at one cell. Figure 7 illustrated the result with high degree of non-homogeneity, where 50% of all new calls are generated at one cell. Clearly, the degree of non-homogeneity has negative impact on the performance of HPCR_CB (HPCR as well), although HPCR_CB schemes still show great improvement over GC scheme. As shown in Figure 7, the performance improvement is reduced by approximately one order of magnitude compared to that of homogeneous traffic condition (Figure 4).

Next, let us look at the comparison of HPCR_CB with the CC scheme, which is done on the basis of performance optimization. The optimization problem is stated as follows:

Minimize the new call blocking probability B_n such that
$B_h \leq M$, where M is the constraint on the handoff blocking probability.

In table 1, each column represents the minimum new call blocking rates for various schemes at the same constraint of handoff blocking rate for a certain traffic load. Consequently, a scheme with the lowest new calls blocking rate outperforms other schemes at that traffic load. As shown in the table, HPCR2_CB surpasses all other schemes including CC for the full range of traffic except 80% load, which is a extremely rare case for real-life situation.

SCHEME TRAFFIC	40% load	50% load	60% load	70% load	80% load
HO Constraints	0.000001	0.000001	0.000008	0.000013	0.000021
GC	0.177708	0.280087	0.376446	0.419064	0.492828
HPCR2	0.156445	0.298728	0.359779	0.42124	0.490145
CC	0.023576	0.070321	0.158036	0.211571	0.290852
Improvement over GC	87%	75%	58%	50%	41%
Improvement over HPCR2	85%	76%	56%	50%	41%
HPCR2_CB	0.00437	0.026018	0.120287	0.199821	0.328856
Improvement over GC	98%	91%	68%	52%	33%
Improvement over HPCR2	97%	91%	67%	53%	33%
Improvement over CC	81%	63%	24%	6%	-13%

Table 1. Comparison of New Call Blocking Rates with Constraints on HO Blocking Rate (reuse distance = 3)

5. CONCLUSION

In this paper, we presented a new handoff prioritization scheme in cellular networks. The scheme, called PCR_CB, is the integration of the predictive-based channel reservation (PCR) and the channel borrowing strategy similar to Load Balancing with Selective Borrowing (LBSB) scheme. The implementation of the predictive-based scheme takes advantage of the recent advancement on mobile position measurement technology. Applying UE-based method, the position information is periodically relayed to the base station which then predicts the next cell in the path of the mobile. The paper discussed the simulation model and presented the results which show the improvement of multiple orders of magnitude over original PCR schemes and GC based scheme. Both homogeneous and non-homogeneous traffic conditions were included in the study. We also compared the PCR_CB schemes with the Channel Carrying (CC) scheme on the basis of performance optimization and the advantage of PCR_CB over CC was clearly demonstrated. Future work includes the performance study of the PCR with multiple channel allocation (multimedia) and the design of adaptive scheme based on PCR_CB.

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