A Cell-based Call Admission Control and Bandwidth Reservation Scheme for QoS Support in Wireless Cellular Networks

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Abstract The deployment of multimedia services in wireless cellular networks calls for network resource management strategies for providing Quality-of-Service (QoS) support to mobile users. An important issue in wireless QoS provisioning is the prevention of handoff drops. We develop a cell-based call admission control (CAC) and bandwidth reservation scheme that aims at minimizing the handoff dropping probability. Our scheme reduces complexity by using simple cell-wide information in neighboring cells. We evaluate the performance of our scheme through simulation under various load levels and user mobility conditions. Our results show that, when compared with a number of existing bandwidth reservation schemes as well as with no reservation scheme, our scheme achieves lower handoff dropping probability and comparable bandwidth utilization.

1 INTRODUCTION

The deployment of multimedia services in wireless cellular networks calls for network resource management strategies for providing Quality-of-Service (QoS) support to mobile users. Multimedia data, for example, the audio and video data in video telephony, has higher bandwidth requirement than traditional data. In order to maintain acceptable call quality, certain amount of bandwidth must be available during the entire session of a call. Given limited total bandwidth in each cell in a wireless cellular network, call admission control (CAC) is needed to ensure that accepting a new call would not jeopardize the quality of already-accepted on-going calls. In addition to call admission control to new calls, differing from the case of wired networks, there is the issue of handoff call handling in wireless cellular networks. A handoff of an ongoing call occurs when the mobile terminal carrying the call moves across the boundary of two adjacent cells during the session of the call. If the available bandwidth in the new cell is insufficient, the call has to be terminated; this is called a handoff drop. In general, dropping an on-going call is considered to have a more negative impact to users than blocking a new call. Therefore, various schemes have been proposed in literature to reserve certain amount of cell bandwidth exclusively for handoff calls. Because this amount of bandwidth can not be used by new calls, if there were not many handoff calls, a large amount of the reserved bandwidth may be wasted. This would result in low cell bandwidth utilization. To summarize, the objective in the design of admission control and bandwidth reservation schemes in cellular networks is to achieve low new call blocking probability (CBP), low handoff call dropping probability (CDP), and high cell bandwidth utilization (U).

Existing CAC and bandwidth reservation schemes can be classified into static reservation and dynamic reservation schemes. Static schemes always endeavor to maintain a fixed amount of cell bandwidth for handoff calls; this amount, for example, can be specified as a fixed fraction of total cell bandwidth. In dynamic schemes, a variable amount of cell bandwidth is reserved for handoff calls based on the measurement information from either the local cell, the cells in the vicinity, or a combination of both. The measurement information may include, for example, the user mobility patterns and the current cell CDP and CBP information. The aim for obtaining user mobility patterns is to predict the future movement of a mobile terminal since accurate mobility prediction can lead to highly effective bandwidth reservation. However, predicting user mobility can be complex as well as difficult. Since a handoff drop occurs mainly when a cell is overloaded, measuring the cell load may be simpler and more efficient. In this paper, we call the schemes that make use of simple cell-wide information, rather than complex user mobility patterns, when determining the amount of bandwidth to reserve, the cell-based schemes.

We develop a cell-based call admission control and bandwidth reservation scheme that aims at minimizing the handoff dropping probability. In our scheme, a variable-size bandwidth pool in each cell is reserved for and shared by potential handoff calls. When a new call arrives at a cell, an admission test is first performed in the current cell. A bandwidth reservation test is next performed at selected neighboring cells. The actual bandwidth reservation in these neighboring cells occurs only after both tests are successful. For handoff calls, based on how a handoff call is accepted, there are two variants of our scheme: P1 and P2. When a handoff call arrives at a cell, an admission test is first performed in this cell. In P1, same as the case of a new call, a reservation test is next conducted in selected neighboring cells. If both tests are successful, the handoff call is accepted and bandwidth is reserved in these neighbors. In P2, a handoff call is accepted without reservation tests or actual reservation in any neighbor as long as it passes the admission test at the local cell. In both variants, the amount of bandwidth reserved for handoff calls is determined based on the number of existing calls in the neighbors. We evaluate the performance of our scheme through simulation under various load levels and user mobility conditions. The performance measures that we used include CDP, CBP, U, as well as a comprehensive score, called "total system award". The total system award is defined as a weighted sum of CDP, CBP, and (1-U); it represents the overall performance of a given scheme. Our results show that, when compared with a number of existing bandwidth reservation schemes as well as with no reservation scheme, our scheme achieves lower handoff dropping probability, comparable bandwidth utilization, and superior total system award. The performance gain of our scheme is more clearly shown when the load is heavier and the mobility level is higher.

This paper is organized as follows. In Section 2, related work on QoS provisioning in wireless cellular networks is reviewed. Our proposed scheme is described in Section 3. The simulation model and other schemes that we used for performance evaluation are presented in Section 4. Simulation experiments and results are reported in Section 5. Finally, Section 6 contains a summary of our findings and a discussion of future work.

2 RELATED WORK

Much research has been carried out on QoS provisioning in wireless cellular networks. The most prominent ones are on designing CAC and bandwidth reservation schemes. As mentioned in the last section, existing schemes can be classified into static and dynamic reservation schemes. Static schemes [1, 2] are simple to implement, but may not be able to adjust to changing traffic conditions. In contrast, in dynamic schemes, the amount of bandwidth reserved is dynamically adjusted based on the information from either the local cell or nearby cells. When the adjustment is based on the information from the local cell, a common objective is to perform CAC and bandwidth reservation adaptively to meet a given target performance metric, for example, a target CDP [3, 4, 5]. If the current CDP is lower than the target CDP, the amount of bandwidth reserved may be reduced so that more new calls can be accommodated. On the other hand, if the current CDP is higher than the given target, the amount of reserved bandwidth is increased to accept more handoff calls.

When the adjustment of reserved bandwidth is based on the information from nearby cells, the objectives may include meeting a target CDP, as described above. They may also include minimizing CDP and CBP, and maximizing bandwidth utilization. Based on the type of information collected, these schemes can be further classified into user-mobility based schemes and cell-based schemes. In user-mobility based schemes, bandwidth is reserved based on sophisticated prediction of future mobile movement. In [6], a shadow cluster concept is proposed to estimate the future resource availability and to control the CDP. In [7], Yu *et. al.* propose another scheme that uses the user mobility prediction to keep the CDP below a target level. The actual reservation, however, is based on handoff dropping events rather than mobility prediction. Other mobility-based schemes include [8, 9, 10, 11, 12]. In general, calculating mobile mobility patterns can be complex and expensive and the efficiency of mobility-based schemes strongly depends on the accuracy of the prediction.

In cell-based schemes, the amount of bandwidth reserved is mainly determined by simple cell-wide information rather than user mobility patterns [5, 13, 14, 15]. The cell-wide information may include, for example, the number of handoff calls dropped [5] and the total number of on-going calls in all neighbors [14]. In [13], a probabilistic resource estimation and resource reservation scheme is proposed. In this scheme, the amount of bandwidth reserved is determined based on the average bandwidth requirement of a call and the probabilities that a call enters neighboring cells. In [15], an adaptive CAC and bandwidth reservation scheme is proposed, which reserves bandwidth for handoff calls in all six neighboring cells. The amount of bandwidth reserved is determined by either the number of calls in neighboring cells or the largest bandwidth requirement requested from neighboring cells. When the number of calls in neighboring cells is used, the amount of bandwidth reserved is calculated by multiplying the average bandwidth requirement and the number of calls.

When performing CAC and bandwidth reservation, two techniques have been widely used in the literature to improve the performance of multimedia delivery. They are rate adaptation [3, 13, 15, 16, 17, 18] and bandwidth borrowing [3, 10, 15, 17, 19, 20]. Rate adaptation schemes are based on the observation that multimedia data may tolerate certain degree of quality degradation when operating with a reduced amount of bandwidth. Using these schemes, when in time of heavy load, bandwidth allocated to existing calls may be temporarily decreased to a minimum requirement in order to accommodate more calls. Bandwidth borrowing schemes assume multi-service-class scenarios, for example, incoming calls can be categorized into either a real-time class or a best-effort class; the former is considered to be more bandwidth-constricted than the latter. When at heavy load, bandwidth allocated to less bandwidth-constricted classes may be borrowed by more bandwidth-constricted classes. This may lead to better performance, for example, lower CDP, for calls of more bandwidth-constricted classes. In this paper, we focus on the cases when all traffic classes are bandwidth-constricted and all bandwidth requirements for calls are fixed. Thus we do not use rate adaptation and bandwidth borrowing techniques in this study. It should be noted, however, that these techniques can be used to further improve the performance of our scheme.

3 DESCRIPTION OF OUR SCHEME

We consider a two-dimensional mobile network with a cellular infrastructure as shown in Figure 1. Each cell is surrounded by six neighboring cells. We assume that each cell has the same size and is assigned the same fixed amount of bandwidth. Each cell is managed by a base station (BS), which handles call arrivals, call departures, as well as bandwidth reservation. We assume that each BS is equipped with wired connections to the base stations in neighboring cells. Thus the communication among base stations does not consume the wireless bandwidth and is considered to be inexpensive. We also assume that each mobile terminal (MT) is equipped with Global Positioning System (GPS) which can be used to tell the moving speed and moving direction of an MT in real-time. In this study, we do not consider the soft handoff scenarios [21, 22], in which an MT may communicate with more than one BS at the same time.

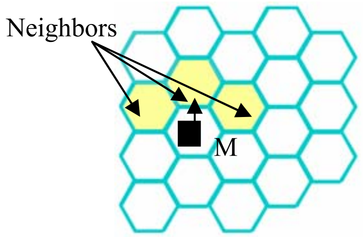

Figure 1: Cellular network topology

3.1 Algorithm Overview

When a MT arrives at a cell, the BS obtains the following call information from the MT: call type, bandwidth requirement, and possibly the moving direction. Call type indicates whether the arriving MT carries a new call or a handoff call. Bandwidth requirement specifies the amount of bandwidth requested by this call in bit-per-second (bps). The moving direction may be used to determine which neighboring cells shall be informed for bandwidth reservation purposes in observance of this call. For example, if the MT is moving to the north direction as shown in Figure 1, the three highlighted neighboring cells along the MT moving direction, namely the north, the northwest, and the northeast, may be informed.

If an arriving call is a new call, an admission test is first performed in the local cell. A bandwidth reservation test is next performed at selected neighboring cells. If both tests are successful, this new call is accepted; these neighboring cells make actual bandwidth reservation. For handoff calls, based on how a handoff call is accepted, there are two variants of our scheme: P1 and P2. If an arriving call is a handoff call, an admission test is first performed in the local cell. In P1, same as the case of a new call, a reservation test is next conducted in selected neighboring cells. If both tests are successful, the handoff call is accepted and the bandwidth is reserved in these neighbors. In P2, a handoff call is accepted without any reservation test or actual reservation in neighboring cells as long as it passes the admission test at the local cell. When a MT leaves a cell, reserved bandwidth is released in selected neighbors. We next describe the admission test, the bandwidth reservation, and the bandwidth release procedures in sequence.

3.2 Admission Test

Let C denote the total bandwidth of a cell. We partition the total bandwidth into three logical portions: Bused, Ba, and Br as shown in Figure 2.

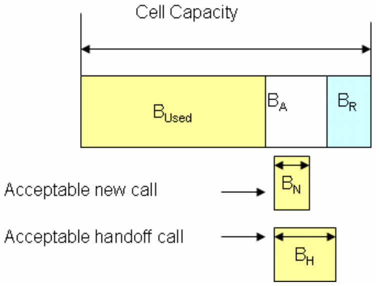

Figure 2: Logical view of cell bandwidth partitions

Bused is the amount of bandwidth currently in use by on-going calls. Br is the amount of bandwidth reserved for handoff calls. Ba is the remaining available bandwidth and can be obtained by using: C – Bused – Br. Let bw denote the amount of bandwidth requested by an incoming call. The admission test for P1 is given in Figure 3.

```
// CALL ADMISSION TEST FOR P1
if new call
    if $bw \le C - Br - Bused$
        select a set of neighboring cells
        reservation test in these neighbors (*a)
        if successful in all, reservation in these cells (*b)
            $Bused = Bused + bw$      // Br does not change
            increase the number of calls in the current cell
        else block this new call
    else block this new call
else // a handoff call
    if $bw \le C - Bused$
        Determine handoff probability p, with probability p
            select a set of neighboring cells
            reservation test in these neighbors (*a)
            if successful in all, reservation in these cells (*b)
                $Ba = C - Bused - Br$   // available bandwidth
                $Bused = Bused + bw$
                if $bw > Ba$
                    $Br = Br + Ba - bw$
                increase the number of calls in the current cell
            else handoff drop
        With probability (1-p)
```

```
24          Ba = C – Bused – Br   // get available bandwidth
25          Bused = Bused + bw
26          if bw > Ba
27              Br = Br + Ba - bw
28          increase the number of calls in the current cell
29    else handoff drop
```

Figure 3: Admission test for P1

Upon arrival of a new call, the algorithm compares its bandwidth requirement, bw, with the available bandwidth, C - Br - Bused (line 3). In contrast, for a handoff call, the algorithm compares its bandwidth requirement, bw, with the sum of the available bandwidth and the reserved bandwidth, C - Bused (line 12). A new call is accepted only if (i) there is enough available bandwidth in the local cell, and (ii) the reservation tests are successful in all selected neighbors (lines 3-10). For handoff calls, if the cell has enough bandwidth (line 12), a handoff probability p is calculated based on the number of handoffs that the call has experienced. With probability p, reservation tests and subsequent reservation are performed in neighboring cells (lines 13-22). With probability (1-p), the handoff call is accepted without incurring any reservation in neighbors (lines 23-28). The handoff probability signifies the probability that the call will terminate in the local cell. We assume that a call that has experienced more handoffs is more likely to terminate. The formula we used for calculating p is p = 1 / (1 + Nh), where Nh is the number of handoffs the call has had.

In P1, because all handoff calls may incur reservation test in neighbors, a call may experience multiple reservation tests during its lifetime as the MT moves across multiple cells, even though it has already undergone a reservation test when the MT first arrives at the network. To reduce CDP, in P2, we remove the reservation test in neighboring cells for handoff calls. The admission test for P2 is shown in Figure 4; only the changed portion from P1 is included (Note the line numbers). It can be seen that, comparing to P1, in P2, the admission test for handoff calls is much simplified.

```
// SEGMENT FROM ADMISSION TEST FOR P2
11 else // a handoff call
12    if bw <= C - Bused
13        Ba = C – Bused – Br   // get available bandwidth
14        Bused = Bused + bw
15        if bw > Ba
16            Br = Br + Ba - bw
17        increase the number of calls in the current cell
18    else drop this handoff call
```

Figure 4: Segment of admission test for P2

In Figure 3 lines 4 and 14, a set of neighbors are selected for reservation. This set can be determined based on simple MT information such as velocity and moving direction. In our experiments, we define three mobility levels based on MT velocity. For low mobility MT's, all neighbors are chosen for reservation. For medium and high mobility MT's, only the three neighboring cells along the MT moving direction are selected for reservation.

3.3 Reservation Test and Bandwidth Reservation

In this subsection, we describe the reservation test and the possible subsequent bandwidth reservation that is invoked by the admission tests presented in the last subsection. The invocation of these two procedures are indicated by (*a) and (*b) in Figure 3 respectively. The reservation test for both P1 and P2 is shown in Figure 5. The corresponding bandwidth reservation procedure is very simple, and is shown in Figure 6.

```
// (*a) RESERVATION TEST IN SELECTED NEIGHBOR
1 get total number of calls, N, in all neighbors
2 determine amount of bandwidth r_bw using N + 1
3 if r_bw <= C – Bused
4    return successful
5 else
6    determine amount of bandwidth r_bw' using N
7    if r_bw' > C - Bused
8        Br = C – Bused   // Ba = 0
9    else Br = r_bw'
10   return fail
```

Figure 5: Reservation test in selected neighbors (P1 and P2)

The reservation test uses the total number of on-going calls in all neighbors plus the current call to determine r_bw, the amount of bandwidth to reserve. If there is enough free bandwidth, the test is passed (lines 3-4). Otherwise, the test is unsuccessful (line 11). If the test is unsuccessful, to more closely match the current load condition, the algorithm re-adjusts the reservation pool using the current total number of calls in all neighbors (lines 6-10). The actual reservation is carried out only when the reservation test is successful. This happens when there is enough free bandwidth (i.e., the predicate in line 3 of Figure 5 is evaluated to true). The algorithm simply assigns r_bw to Br.

```
// (*b) RESERVATION IN SELECTED NEIGHBORS
// continuing the algorithm in Figure 5
    Br = r_bw     // get available bandwidth
```

Figure 6: Reservation in selected neighbors (P1 and P2)

Both the reservation test and the actual bandwidth reservation depend on a function to determine a proper amount of bandwidth to reserve. In our scheme, this amount is determined based on the number of on-going calls in each selected neighboring cell (see lines 2 and 6 in Figure 5). We defer the description of how we determine this amount to Section 5.

3.4 Bandwidth Release

When an MT leaves a given cell, the selected neighboring cells are informed. These cells release the reserved bandwidth using the algorithm shown in Figure 7. Essentially, the algorithm re-adjusts the amount of bandwidth to reserve based on the current total number of calls in all neighbors.

```
// BANDWIDTH RELEASE IN SELECTED NEIGHBORS
get total number of calls, N, in all neighbors
determine amount of bandwidth r_bw using N
if  r_bw > C - Bused
    Br = C - Bused    // Ba = 0
else
    Br = r_bw
```

Figure 7: Reservation release in each selected neighbor

This concludes the description of our scheme.

4 SIMULATION MODEL

In this section, a simulation model is developed to evaluate the performance of the proposed scheme. We first describe other schemes that we implemented for performance evaluation. The network model, the traffic model, and the performance measures that we used are next presented.

4.1 Implemented Schemes

Besides P1 and P2, three other schemes are implemented in our model. These are OKS [15], static reservation, and no reservation. The OKS scheme is very similar to ours except that (i) bandwidth reservation is performed in all neighbors, (ii) the amount of bandwidth reserved is different from ours, this will be detailed in Section 5, and (iii) reservation is always conducted for handoff calls. The pseudo code description of OKS scheme is given in Figure 8.

```
// CALL ADMISSION TEST FOR OKS
if new call
    if bw <= C – Br - Bused
        reservation test in all neighbors (*a)
        if successful in all, reservation in neighbors (*b)
            Bused = Bused + bw      // Br does not change
            increase the number of calls in the current cell
        else block this new call
    else block this new call
else // a handoff call
    if bw <= C – Bused
        reservation test in all neighbors (*a)
        if successful in all, reservation in neighbors (*b)
            Ba = C – Bused – Br   // get available bandwidth
            Bused = Bused + bw
            if bw > Ba
                Br = Br + Ba - bw
            increase the number of calls in the current cell
        else handoff drop
```

Figure 8: OKS scheme implemented

Static scheme and no reservation scheme are two baseline schemes. In our model, the amount of reserved bandwidth in static scheme is specified as a percentage α of the total cell bandwidth, where α is an input parameter. Figure 9 contains the pseudo code description of the static scheme. Note that the bw in Figure 9 is the bandwidth requirement of the incoming or outgoing call.

```
// CAC for STATIC RESERVATION SCHEME
if new call
    if bw <= C – Bused – Br
        Bused = Bused + bw
    else block this new call
else   // a handoff call
    if bw <= C – Bused
        Bused = Bused + bw
        if C – Bused <= α C
            Br = C – Bused
    else handoff drop

// BANDWIDTH RELEASE IN STATIC SCHEME
Bused = Bused - bw
if C - Bused > α C
    Br = α C
else Br = C – Bused
```

Figure 9: Algorithm for static reservation scheme

The no reservation scheme is very simple. When a call arrives at a cell, if there is enough free bandwidth (C – Bused > bw), the call is accepted, otherwise, it is rejected. When a call leaves the cell, the amount of used bandwidth is updated (Bused = Bused – bw).

4.2 Network Model

Our network model consists of a total of 100 cells arranged in a 10 by 10 square region with wrap-around border cells. Each cell has six neighboring cells, namely, the north, the northeast, the southeast, the south, the southwest, and the northwest. Each cell is assumed to have a fixed cell bandwidth of 5Mbps. The diameter of each cell is assumed to be fixed and is an input parameter.

4.3 Traffic Model

We assume that all calls arrive at the network from a Poisson process with rate λ calls/second. For each new call, the arriving cell is randomly selected from all 100 cells. The call duration is assumed to be exponentially distributed with mean μ^{-1} seconds. Each call is either a voice call or a video call. The bandwidth requirement for a voice call is assumed to be 30 Kbps; the bandwidth requirement for a video call is assumed to be 256 Kbps. Similar assumptions have been made in prior studies [15, 23]. Half arrivals are voice calls, and the other half are video calls. The call velocity is assumed to be uniformly distributed between [min, max] Km/hr. The initial direction of each call is randomly chosen. The cell residence time of each call is determined by cell diameter divided by the velocity of the call.

Three mobility levels are defined in our model and are used in our experiments as an input parameter. These are: low, medium, and high mobility levels. These levels differ in MT velocity, call duration, next cell to enter at handoff, cell diameter, and the set of neighbors that are selected for reservation. The properties of these mobility levels are summarized in Table 1. The low mobility level is used to model an urban shopping area. All mobile users are assumed to be pedestrians. The average call duration is 150 seconds for voice and 250 seconds for video, which is slightly longer than the other two mobility levels. These values are selected based on existing studies on telephone call durations [24] and streaming multimedia durations [25]. The cell size is assumed to be 200 meters, which is smaller compared to the other two mobility levels. The medium mobility level is used to model a city driving scenario, in which all mobile users are assumed to be on cars. The high mobility level is used to model a busy highway intersection area. Such an intersection may be located outside of, but close to, a large city.

Table 1: Three mobility levels in our model

Mobility level	**Low**	**Medium**	**High**
[min, max] (km/hr)	[2, 8]	[20, 80]	[80, 100]
Mean call duration (seconds)	Voice: 150 Video: 250	Voice: 120 Video: 180	Voice: 120 Video: 180
Next cell to enter at handoff	All neighbors with same probability	All neighbors with different probability	Three neighbors on moving direction
Cell diameter (km)	0.2	1	1
Selected neighbors for reservation	All six neighbors	Three neighbors on moving direction	Three neighbors on moving direction

In Table 1, for the medium mobility level, when determining the next cell a call will enter at handoff, the following probabilities are used: straight 0.5, straight left 0.15, straight right 0.15, backward left 0.075, backward right 0.075, and backward 0.05. In the high mobility level, the three neighboring cells along the MT direction are selected with the same probability (1/3).

4.4 Performance Measures

Both system-wide and cell-wide performance results were obtained in our experiments. To save space, we only report the aggregated system-wide performance in this paper. Four performance measures of interest are used. These are:

(i) CDP, this is defined as the fraction of handoff calls that are dropped

(ii) CBP, this is defined as the fraction of new calls that are blocked

(iii) U, bandwidth utilization at a given cell. It is defined by:

$$U = \frac{\sum_i T_i \times Bused}{T \times C} \qquad (1)$$

T denotes the total simulation time of a simulation experiment. T_i is the duration in simulation time between the $(i-1)^{th}$ event and the i^{th} event in a discrete-event simulation. The aggregated utilization is defined to be the arithmetic mean of utilization of all cells.

(iv) Total system award, Ω. This is a comprehensive score and is defined in Eq. (2). The three coefficients a, b, and c are used to convey the relative importance or weight of CDP, CBP, and U respectively. In this paper, we choose the values of a, b, and c so that the sum of them is one. Total system award represents the overall performance of a given scheme. Note that the lower the value of Ω, the better the performance.

$$\Omega = a \times CDP + b \times CBP + c \times (1 - U) \qquad (2)$$

5 EXPERIMENTS AND SIMULATION RESULTS

Using the simulation model described above, simulation experiments were carried out to evaluate the performance of our proposed scheme. Each experiment consists of six replications; the sample mean and the 99% confidence interval are computed and reported for each experiment. We first describe the experiments that we conducted and the amount of bandwidth reserved in our experiments. The performance results are reported afterwards.

5.1 Simulation Experiments and the Amount of Bandwidth Reserved

There are three major input factors to our experiments. The first one is the reservation scheme. There are five schemes: P1, P2, OKS, static reservation, and the “no reservation” scheme. For static reservation, a value of 10% is used in most experiments for α, the percentage of bandwidth reserved. The second input factor is the user mobility level, namely low, medium, and high. The third input parameter is the offered load per cell, L. The formula to calculate L is

$$L = (0.5 \times 30 + 0.5 \times 256)\frac{\lambda_0 \mu^{-1}}{C} \qquad (3)$$

The first term in Eq. (3) computes the average bandwidth requirement per call in Kbps. λ_0 denotes the average call arrival rate at each cell. In our model, $\lambda_0 = \lambda / 100$. μ^{-1} is the average call duration, and C is the cell bandwidth. In our experiments, six levels of L, ranging from 0.5 to 3 in steps of 0.5, are used.

The amount of bandwidth that we used in bandwidth reservation for both OKS and our scheme is listed in Table 2. In OKS, the amount of bandwidth reserved in a cell is based on the number of calls in all six neighbors and is calculated roughly by multiplying the average bandwidth requirement per call with the average number of calls [15]. Therefore, different amount of bandwidth may be reserved in different neighboring cells. However, since it is unlikely that all the calls in neighbors move to the same cell at the same time, in our scheme, we reserve only one sixth of the amount in OKS (see the last column in Table 2).

Table 2: Bandwidth reserved based on the number of calls

Number of calls	OKS scheme	P1 and P2
0-5	512 kbps	85 kbps
6-10	1024 kbps	170 kbps
11-20	2048kbps	341kbps
21 or more	3072kbps	512 kbps

5.2 Results on CDP, CBP, and U

In Figure 10, we plot the results for the low mobility level case. The three graphs in this figure correspond to the results for CDP, CBP, and U respectively. It can be observed that as the level of offered load is increased, all of CDP, CBP, and U become higher. Among the five schemes experimented, P2 achieves the lowest CDP; when $L = 3$, the CDP is 3.4% for P2, 3.8% for static scheme, 13.2% for P1, and above 20% for the rest schemes. As to the results on CBP and U, the no reservation scheme had the best performance; P1, P2, and the static scheme resulted in similar performance. For all three performance measures, OKS had the worst performance among all the schemes. Similar observations can be made for the medium and high mobility level cases. Their results are plotted in Figures 11 and 12 respectively. For medium mobility level, at $L = 3$, the CDP is 2.7% for P2 and 4.6% for static scheme; for high mobility level, these values become 3.0% and 7.1%. We conclude that the variant P2 of our scheme achieves the best performance in terms of CDP, and can achieve comparable performance with other reservation schemes in terms of CBP and U.

5.3 Results on Total System Award

In order to gain a view on the overall performance of each scheme, we also obtained the results on the total system award, Ω. We selected the set of weights (0.8, 0.1, 0.1) for the set of coefficients (*a, b, c*) in Eq. (3). This set places heavy weight on CDP and light weights on CBP and U. The results are plotted in Figures 13; three graphs are for the low, medium, and high mobility levels, respectively.

It can be observed that (i) both P2 and the static scheme achieve the best performance for all load levels and all mobility levels, (ii) as the level of load is increased, the gain from resource reservation is more clearly shown, this is seen from a larger gap in between no reservation scheme and P2, (iii) between P2 and the static scheme, at low and medium mobility levels, their performance is very close; at high mobility level, P2 has slightly better performance and the performance lead is slightly larger when the level of load in increased. We conclude that in terms of total system award, our proposed scheme P2, along with the static scheme, achieve the best overall performance among all other schemes experimented. The performance gain of our scheme is more clearly shown when the load is heavier and the mobility level is higher.

5.4 Selecting the Amount of Bandwidth to Reserve

Our last experiment is concerned with the selection of an optimal amount of bandwidth for reservation. For all CAC and bandwidth reservation schemes, a challenge is to determine an optimal amount of bandwidth to reserve. In this study, we take an experimental approach to addressing this issue. From the results in the last two subsections, we found that the top performers among reservation schemes are P2 and the static scheme. For each of these two schemes, we vary the amount of reserved bandwidth, and plot the total system award Ω versus the amount of bandwidth reserved for the medium mobility level. The weight set (0.6, 0.2, 0.2) is used for calculating Ω. Comparing to the set of weights used in the last subsection, this set of weights places relatively heavy weight on CDP and moderate weights on CBP and U. The results are plotted in Figures 14 and 15, for P2 and the static scheme, respectively.

For P2, a parameter β is defined. The amount of bandwidth reserved is obtained by multiplying the amount in Table 2 for OKS with β. Therefore, $\beta = 0$ corresponds to the no reservation case; $\beta = 1/6$ corresponds to the amount used by P1 and P2 in the experiments reported in the last two subsections. We varied the range of β from 0 to 1/3. It can be observed that the best performance is achieved when the value of β is in the range of 1/6 to 1/8. For the static scheme, the best performance is achieved when the value of α is in the range of 10% to 12.5%. These results agree with our belief that both "no reservation" and "excessive reservation" can lead to inferior performance; there exists an optimal amount of bandwidth, with which the best overall performance can be achieved.

6 CONCLUSION

In this paper, we developed and evaluated a new cell-based admission control and bandwidth reservation scheme that aims at minimizing the handoff dropping probability while maintaining good CBP and bandwidth utilization performance. In our scheme, only simple cell-based information, rather than the more complex user mobility pattern, is used to determine the amount of bandwidth reserved, and only one sixth of the total bandwidth corresponding to the number of existing calls in all neighbors is reserved in each selected neighboring cell. This significantly improves the algorithm performance. We also found that by removing the bandwidth reservation for handoff calls, better performance can be achieved. In addition to CBP, CDP, and U, in this paper, we defined a new performance metric, called the total system award that represents the overall performance of a CAC scheme. Our experiments show that our scheme, namely P2, achieves the best overall performance. In this study, the size of each cell is assumed to be the same and every cell has the same reservation policy for a handoff call. As a direction for future work, the scenario when different reservation policies may be employed at different cells can be investigated, this employment can be based on either the cell size or other cell properties.

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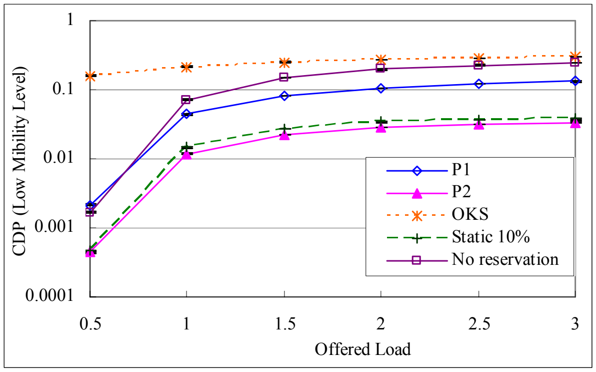

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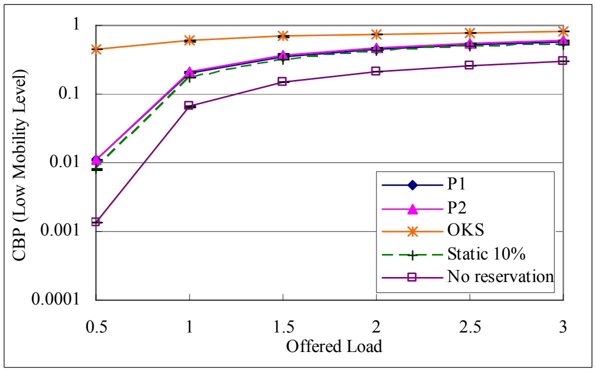

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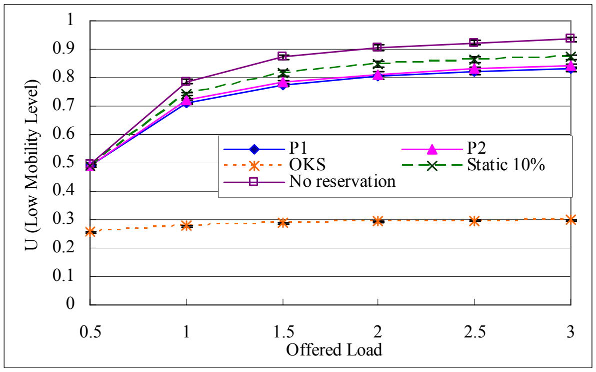

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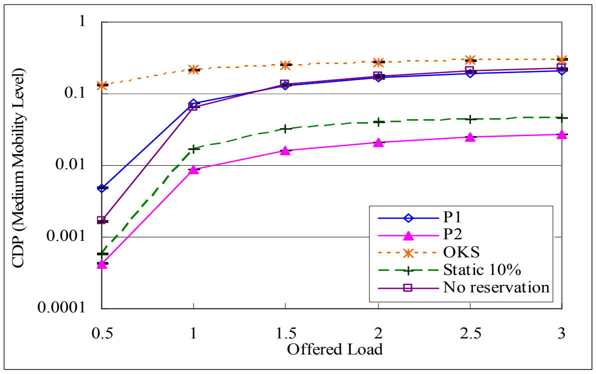
Figure 10: Performance for Low Mobility Level case



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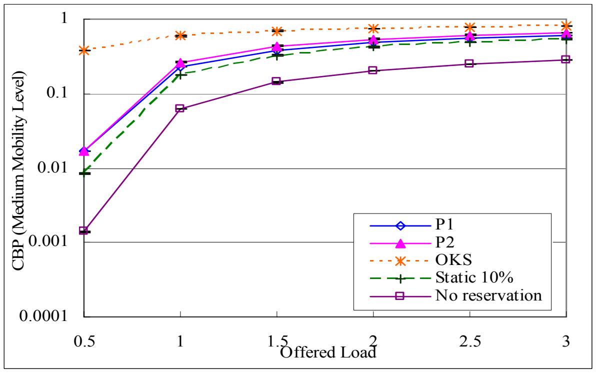

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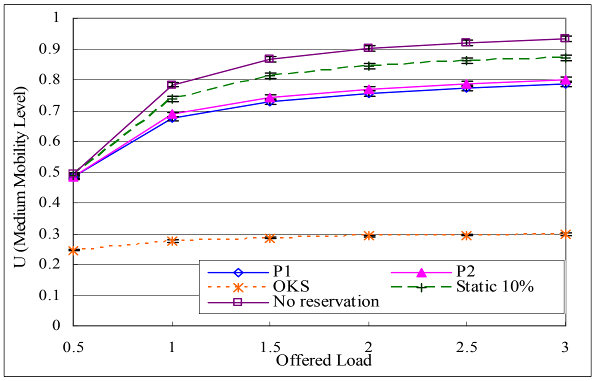

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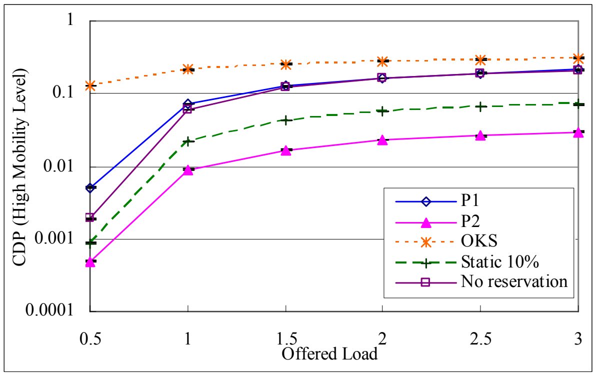
Figure 11: Performance for Medium Mobility Level case



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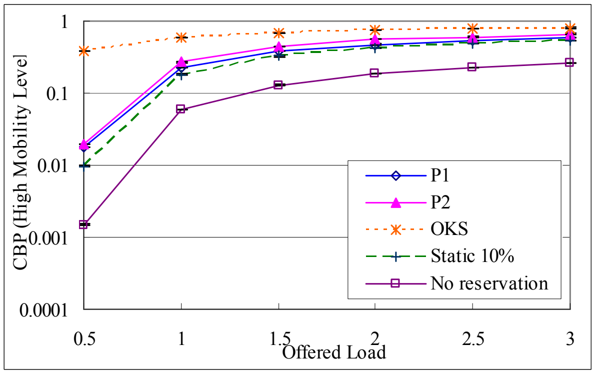

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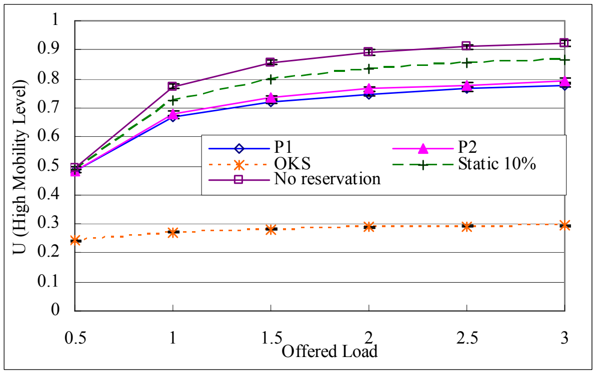

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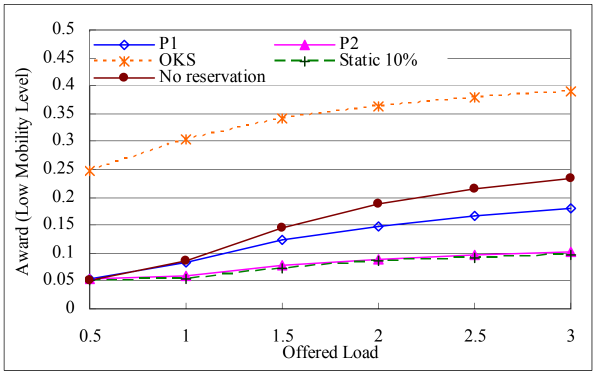
Figure 12: Performance for High Mobility Level case



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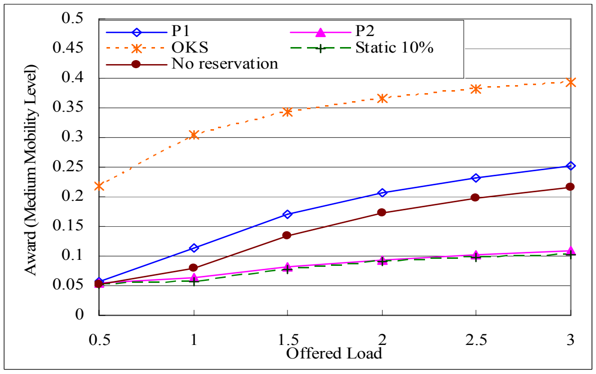

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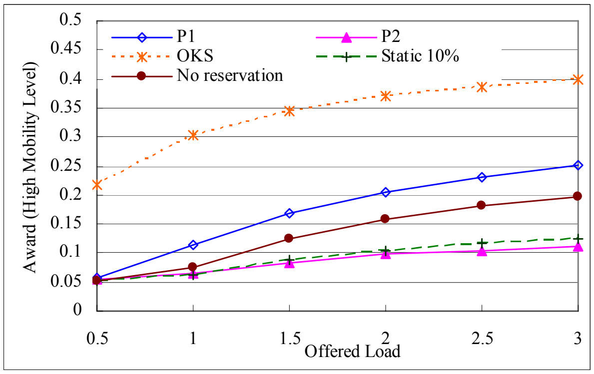

(iii)

Figure 13: Total system award (weight 0.8, 0.1, 0.1)

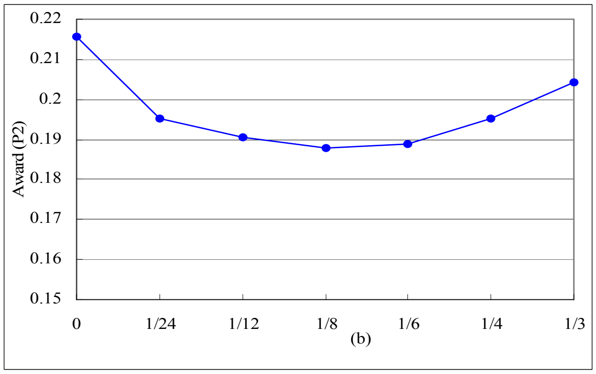

Figure 14: Optimal total system award (P2)

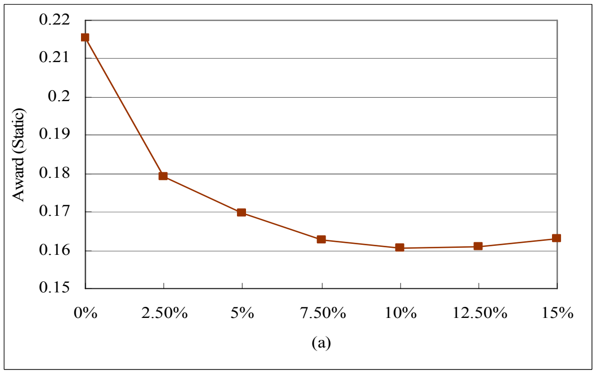

Figure 15: Optimal total system award (static scheme)