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

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Abstract

Call admission control (CAC) and bandwidth reservation are key mechanisms in providing quality-of-service (QoS) support in wireless cellular networks. Many existing CAC and bandwidth reservation schemes are user-mobility based where bandwidth is reserved based on sophisticated prediction of future mobile movement. 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. Cell-based schemes, in contrast, emphasize cell-wide information rather than sophisticated mobility prediction, and may be simpler to implement.

In this thesis, I develop a cell-based CAC and bandwidth reservation scheme that aims at minimizing the handoff dropping probability. It reduces complexity by using simple cell-wide information in neighboring cells rather than tracking user mobility patterns. I evaluate the performance of the proposed scheme through simulation under various load levels and user mobility conditions. The results show that, when compared with a number of existing bandwidth reservation schemes, the proposed scheme achieves lower handoff dropping probability and comparable bandwidth utilization.

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Part of this work is reported in a previous paper [20]. For that paper, I conducted literature survey, designed, analyzed and implemented the proposed scheme and the simulation model, conducted experiments, and analyzed the results.

This thesis is dedicated to my family.

Contents

Abstract ii
Acknowledgments iv
Dedication v
Table of Contents vi
List of Tables viii
List of Figures ix
List of Algorithms x

1 Introduction **1**
1.1 Call Admission Control 2
1.2 Thesis Organization 5

2 Related Work **6**
2.1 Static Reservation Schemes 7
2.2 Dynamic Reservation Schemes 7
2.2.1 User-Mobility Based Schemes 8
2.2.2 Cell-Based Schemes 10
Adaptive CAC and Bandwidth Reservation (OKS Scheme) . . 11
Semi-Reservation Scheme 12
Dynamic Grouping Scheme 12
2.3 Rate Adaptation and Bandwidth Borrowing Techniques 15
2.3.1 Rate Adaptation Schemes 15
2.3.2 Bandwidth Borrowing Schemes 16

3 The Cell-Based Call Admission Control Scheme **17**
3.1 Problems of Existing Schemes 17
3.2 Design Decisions of the Proposed Solution 20
3.3 Description of the Proposed Cell-Based Scheme 21
3.3.1 Admission Test 23
3.3.2 Reservation Test and Bandwidth Reservation 27
3.3.3 Bandwidth Release 29

4 Simulation Model and Experimental Results 31
- 4.1 Implemented Schemes 32
  - 4.1.1 OKS Scheme 32
  - 4.1.2 Dynamic-Grouping Scheme 32
  - 4.1.3 Static Reservation Scheme 36
  - 4.1.4 No Reservation Scheme 36
- 4.2 Development of a Performance Model 37
  - 4.2.1 Network Model 38
  - 4.2.2 Traffic Model 38
  - 4.2.3 Analytic Model 40
- 4.3 Performance Measures 40
- 4.4 Simulation Experiments and the Amount of Bandwidth Reserved . . 41
  - 4.4.1 Simulation Model Verification 43
  - 4.4.2 Results on CDP, CBP, and U 45
  - 4.4.3 Results on Total System Award 46
  - 4.4.4 Comparison of P2 and Dynamic Grouping Scheme 48
  - 4.4.5 Selecting the Amount of Bandwidth to Reserve 49

5 Conclusions 55
- 5.1 Contributions 56
- 5.2 Future Work 57

Bibliography 58

List of Tables

4.1 Three mobility levels in the simulation model 39
4.2 Reserved bandwidth based on the number of calls 43
4.3 Comparison of analytical and simulation results 44

List of Figures

1.1 Overview of call admission control at a cell in a wireless network system 3

2.1 The shadow cluster concept 9
2.2 Example of grouping reservation requests 14

3.1 Cellular network topology 22
3.2 Logical view of cell bandwidth partitions 23

4.1 CDP for low mobility level case 44
4.2 CBP for low mobility level case 45
4.3 Bandwidth utilization for low mobility level case 46
4.4 CDP for medium mobility level case 47
4.5 CBP for medium mobility level case 48
4.6 Bandwidth utilization for medium mobility level case 49
4.7 CDP for high mobility level case 50
4.8 CBP for high mobility level case 51
4.9 Bandwidth utilization for high mobility level case 52
4.10 Total system award for low mobility level case (weight 0.8, 0.1, 0.1) . 52
4.11 Total system award for medium mobility level case (weight 0.8, 0.1, 0.1) 53
4.12 Total system award for high mobility level case (weight 0.8, 0.1, 0.1) . 53
4.13 Optimal total system award (P2) 54
4.14 Optimal total system award (Static scheme) 54

List of Algorithms

1 Admission test for a new call in P1 24

2 Admission test for a handoff call in P1 25

3 Segment of admission test for P2 26

4 Reservation test in selected neighbors (P1 and P2) 28

5 Reservation in selected neighbors (P1 and P2) 28

6 Reservation release in each selected neighbor (P1 and P2) 30

7 OKS scheme implemented 33

8 Algorithms for handling new calls in Dynamic-grouping scheme 34

9 Algorithms for handling handoff calls in Dynamic-grouping scheme . . 35

10 Reservation test in Dynamic-grouping scheme 36

11 Algorithms for Static reservation scheme 37

Chapter 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, such as the audio and video data in video telephony, has a higher bandwidth requirement than traditional data. In order to maintain acceptable call quality, a certain amount of bandwidth must be available during the entire session of a call. Given that the total bandwidth in each cell in a wireless cellular network is limited, 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 contrast to real-time traffic which is QoS sensitive, best-effort traffic such as an email and fax is often elastic in terms of QoS requirements. Thus in network resource management, real-time traffic is usually given higher priority over best effort class. In addition, the call admission control is usually performed on QoS-sensitive traffic only so that the number of ongoing calls in a cell can be limited, and the quality of each ongoing call does not degrade below a given level.

In addition to call admission control to new calls, there is the issue of handoff call handling in wireless cellular networks that is nonexistent in wired 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 free bandwidth in the new cell is insufficient, the call must be terminated; this is called a handoff drop. Recent wireless networks pursue small-size cells (e.g. microcells or picocells) to provide higher transmission capacity and to allow more users in a given area. However, small-size cells may lead to more handoffs and thus, increase variability of network traffic conditions. In wireless cellular networks, minimizing handoff drops is still a challenging issue. In general, dropping an on-going call is considered to have a more negative impact on users than blocking a new call. Therefore, CAC is needed to prioritize handoff calls over new calls in order to minimize handoff drops. In what follows, I describe the challenge of CAC in wireless cellular networks and give a brief overview of this thesis.

1.1 Call Admission Control

CAC algorithms in a wireless cellular network often consist of two components: admission control and bandwidth reservation. Admission control limits the number of ongoing calls in a cell so that the performance of ongoing calls does not deteriorate; bandwidth reservation prioritizes handoff calls over new calls. Figure 1.1 illustrates the process of CAC at a cell in a wireless cellular network. The cell base station conducts CAC to decide call acceptance in a cell when a call arrives at the cell. A new call can be accepted only if remaining free bandwidth is larger than the minimum

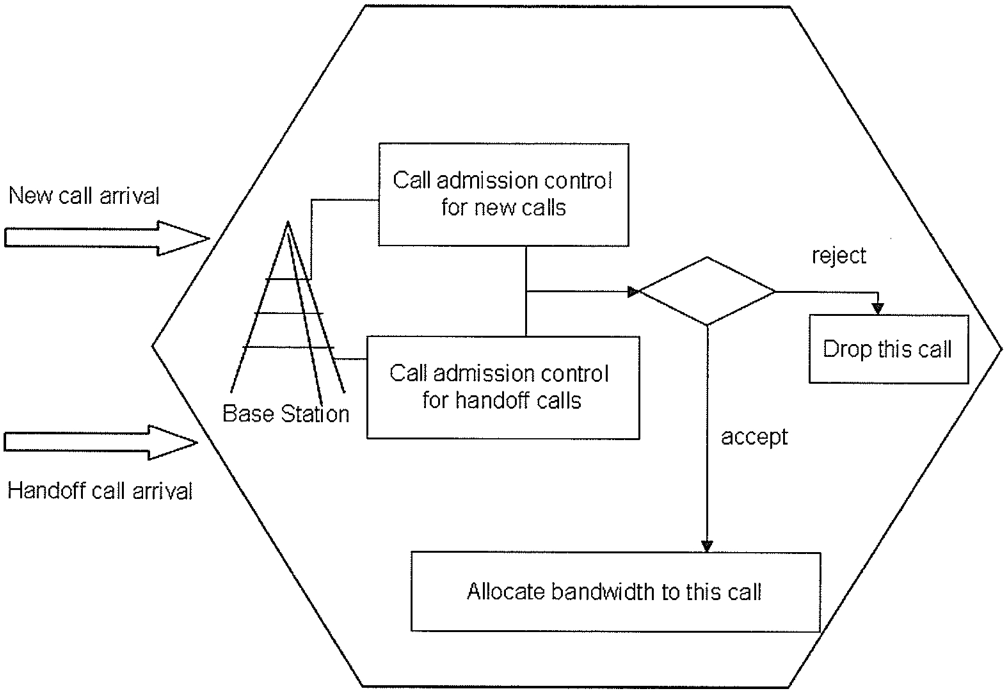

Figure 1.1: Overview of call admission control at a cell in a wireless network system

bandwidth requirement of the new call. The admission control can be conducted based on many quantities such as the number of users and/or the number of handoff drops.

Bandwidth reservation is generally performed by CAC algorithms to prioritize handoff calls over new calls. To give handoff calls a higher priority, certain amount of cell bandwidth is reserved for arriving handoff calls only, and can not be used by new calls at new call arrivals. Because of this, compared to handoff calls, new calls are often admitted under more restricted conditions, and the new call blocking probability often increases when the handoff call dropping probability decreases.

In order to decide on the call acceptance and the amount of bandwidth to reserve, a CAC algorithm needs to manage information gathered from either each ongoing call, for example, bandwidth requirement and the movement history of the mobile, or the total number of ongoing calls in a cell. Various schemes have been proposed in literature to reserve certain amount of cell bandwidth exclusively for handoff calls. The key issue in bandwidth reservation is how much bandwidth to reserve in order to minimize the number of handoff drops, while maintaining high bandwidth utilization. Because this amount of bandwidth reserved cannot be used by new calls, if there were not many handoff calls, a significant portion of the reserved bandwidth may be wasted, which would result in low cell bandwidth utilization. In summary, 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 the 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 purpose in 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. For example, the next cells to be visited by a mobile terminal, the estimated staying time in the current cell and the estimated handoff time can be predicted from the past moving history of the mobile terminal. However, accurately 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 research, I 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*. I propose a cell-based CAC and bandwidth reservation scheme. A simulation model for performance evaluation of the proposed scheme will be presented.

1.2 Thesis Organization

This thesis is organized as follows. Chapter 2 provides an overview of existing CAC schemes in the literature. The approaches taken by existing schemes and their strength and weakness in the literature are discussed in this chapter. Chapter 3 presents the motivation behind the proposed scheme. This chapter also contains the basic algorithms in the proposed scheme. In Chapter 4, the simulation model for the proposed scheme and some selected existing schemes that I used for performance evaluation are described. Simulation experiments and results are also reported in this chapter. Finally, Chapter 5 contains a summary of my findings and concludes with a discussion of future work.

Chapter 2

Related Work

Much research has been carried out on designing CAC and bandwidth reservation schemes for QoS provisioning in wireless cellular networks. There have been comparative evaluations of various schemes in literature. The performance measures reported in the literature for performance comparisons among the existing schemes are mainly CDP, CBP and U. An efficient and effective CAC and reservation scheme should achieve low CDP and CBP, while keep the U high. There is a tradeoff between reducing CDP and CBP. Various approaches have been proposed to reduce or keep CDP under a certain threshold, while increasing bandwidth utilization of a cell by reducing CBP. In this chapter, I first give a general classification of existing schemes, and then review a few important categories.

2.1 Static Reservation Schemes

As mentioned in Chapter 1, existing schemes can be classified into static and dynamic reservation schemes. The static reservation (also called guard channels) scheme [7, 25] has been commonly used for reducing CDP, in which a fixed amount of bandwidth is exclusively reserved for handoff calls. Handoff calls are accepted as long as the amount of reserved bandwidth plus free bandwidth satisfies the bandwidth requirements of the handoff calls, while new calls are rejected if the amount of free bandwidth is less than the bandwidth requirement of the new calls. Static reservation schemes are simple to implement, but may not be able to adjust to changing traffic conditions in wireless networks. If the amount of reserved bandwidth is excessive, new calls may be rejected due to insufficient free bandwidth while there are idle channels in the reservation pool; if the amount of reserved bandwidth is insufficient, many handoff calls may be dropped. Thus, in static schemes, the amount of bandwidth reserved must be carefully determined to minimize the handoff dropping probability while maximizing new calls acceptance to the network system.

2.2 Dynamic Reservation Schemes

In contrast, in dynamic reservation 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 to reserve bandwidth adaptively in order to meet a given target performance metric, for example, a target CDP [9, 13, 15]: if the current CDP is lower than the target, the amount of bandwidth reserved is 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. These two categories are reviewed in sequence.

2.2.1 User-Mobility Based Schemes

In user-mobility based schemes, bandwidth is reserved based on sophisticated prediction of future mobile movement. In [16], a shadow cluster concept is proposed to estimate the future resource availability and to control the CDP. A shadow cluster defines a set of cells around an ongoing call. Basically, the shadow cluster concept assumes that each active mobile has an influence on the neighboring cells on its estimated path of movement. Figure 2.1 shows the shadow cluster concept, in which the shadow cluster is produced by an active mobile terminal (MT). A shadow cluster of a mobile can include a bordering cluster, a set of neighboring cells that shares a common border with the home cell, and a non-bordering cluster. Each cell in a shadow cluster estimates future resource requirements according to the information of the call and its resident mobile. Such information includes bandwidth requirement, current mobile location, velocity, etc. Because the number of cells in a shadow cluster

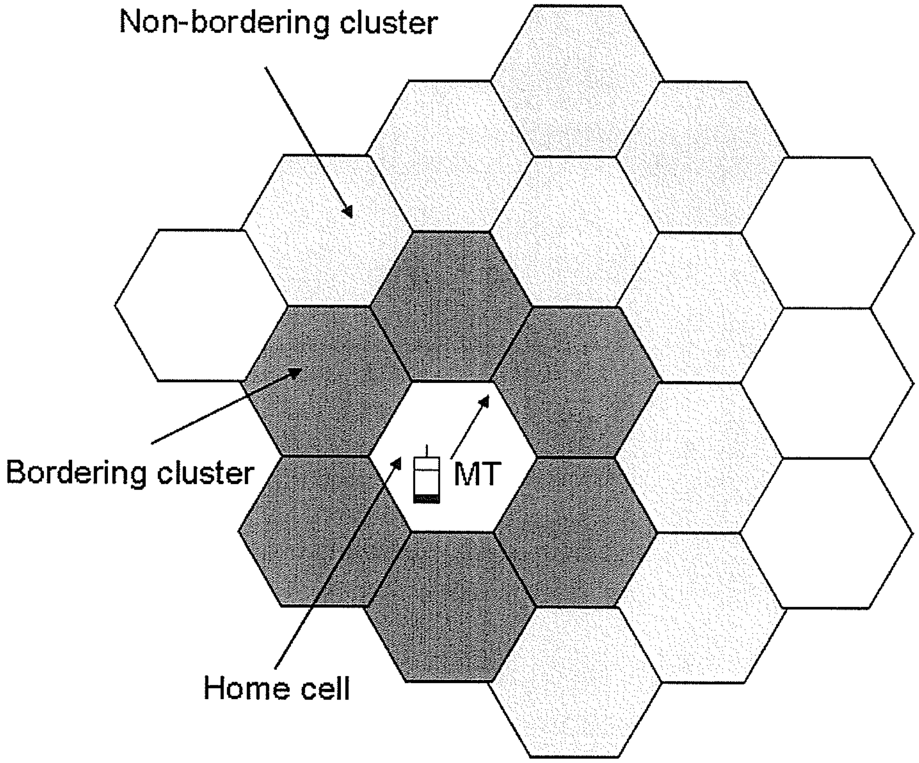

Figure 2.1: The shadow cluster concept

can be large, a large number of messages may be exchanged among cells belonging to the shadow cluster. The results in [6] have shown that the CAC schemes using cluster concepts are not effective to reduce the handoff dropping probability due to their favoring of new calls.

In [26], Yu and Leung propose another scheme that uses the user mobility prediction to keep the CDP below a target level. When a new call arrives, a *mobility tree* is created and the user mobility patterns are learned from the mobility tree. In the tree, each node contains the next cell as well as the probability of entering that cell. Using the mobility tree, this scheme predicts both the next cell to be visited and the handoff time to enter that cell. Once the next cell is chosen, the scheme determines the amount of bandwidth to reserve for the call based on predicted handoff dropping events. CAC calculates the Most Likely Cell-Time (MLCT) of this call; it is a cluster of time intervals at the cells that likely to be visited by this mobile in the future. If reservation request is accepted, the bandwidth for this call is reserved in its MLCT of the next cell.

In [19], Lim et al. propose a differential bandwidth reservation (DBR) algorithm using user profiles to estimate the future mobility of a mobile terminal. In DBR, neighboring cells along the path of an MT are clustered into a sector according to the distance from the current location of the MT, and each sector reserves a different amount of bandwidth for the MT. The number of cells in a sector is determined by a sector angle, and the number of sectors is determined by a distance parameter n from the current cell. These parameters need to be carefully selected; otherwise, the scheme may overestimate the amount of bandwidth to reserve and thus unnecessarily block many new calls. Other mobility-based schemes include [4, 8, 10, 11].

In general, calculating mobile mobility patterns can be complex and expensive due to the high computational overhead for maintaining the mobility pattern information. The efficiency of mobility-based schemes strongly depends on the accuracy of the prediction.

2.2.2 Cell-Based Schemes

In cell-based schemes [2, 14, 15, 22, 24], the amount of bandwidth reserved is mainly determined by cell-wide information rather than sophisticated mobility prediction. The cell-wide information may include, for example, the number of handoff calls dropped [15] and the total number of on-going calls in all neighbors [22]

Adaptive CAC and Bandwidth Reservation (OKS Scheme)

In [24], an adaptive CAC and bandwidth reservation scheme is proposed, in which bandwidth is reserved in all six neighboring cells upon a call arrival. A new call is accepted only if enough free bandwidth is available at the local cell and if the reservation in all six neighbors is successful. A handoff call also undergoes the same bandwidth reservation test with a new call except that the admission control is conducted based on the sum of reserved bandwidth and free bandwidth. The amount of bandwidth reserved is determined by either the number of calls in all six neighboring cells or the largest bandwidth requirement requested from neighboring cells. When the number of calls is used, the amount of bandwidth reserved is calculated by multiplying the average number of calls by the average per-call bandwidth requirement. This scheme reserves bandwidth in all its neighboring cells; it also takes into account all ongoing calls in its neighboring cells when the reservation test is conducted. Since it is unlikely that all the calls in neighbors move to the same cell at the same time, this scheme may result in high CBP and low utilization; moreover, it may result in high CDP because of its conservativeness in reserving bandwidth for handoffs. The results in [14] have shown that in the OKS scheme, the bandwidth utilization rapidly decreases when the network load increases.

Semi-Reservation Scheme

In [14], Kuo et al. propose a probabilistic resource estimation and resource reservation 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. A new call is accepted only if enough free bandwidth is available; otherwise, it will be rejected. Once a new call is accepted into the cell, its residence time in the cell and the handoff time of the call are estimated. According to the estimated information, the base station in the local cell requests bandwidth reservation to neighboring cells. If a neighboring cell does not have enough bandwidth, it sends a soft reject. If the local base station receives a soft reject, it retransmits the reservation request within the estimated cell residence time of the call such that the request can be accepted before the call leaves the local cell. However, since a certain amount of bandwidth is reserved for each individual call, rather than for a collection of calls, the scheme may result in low bandwidth utilization when expected handoff calls do not arrive at the estimated future cells within the estimated handoff time periods, which are called *zombie reservations.* In [2], Chang and Chen have shown that both the connection dropping rates and blocking rates in this scheme became higher and the bandwidth utilization became lower when the call arrival rate increases, since the number of zombie reservations increases and they waste cell bandwidth.

Dynamic Grouping Scheme

In [2], a dynamic-grouping bandwidth reservation scheme is proposed based on the scheme proposed in [14]. In the dynamic-grouping scheme, each cell maintains reservation groups that correspond to different future time intervals. Figure 2.2 shows how the reservation groups are formed in a cell. When a reservation request of an MT $m1$ arrives, specifying its estimated bandwidth requirement, the estimated arrival time, the estimated staying duration, and the estimated handoff probability of its actual arrival at this cell, a new group called group 1 is created whose time interval is the same as the time interval of $m1$. When another MT $m2$ issues a reservation request, if the time interval of $m2$'s reservation request overlaps the time interval of $m1$, the request of $m2$ is entered to group 1. The ending time of group 1 is extended to the ending time of $m2$'s request. The time interval of the request of MT $m3$ does not overlap the time interval of group 1; thus a new reservation group called group 2 is created. This way, each group contains per call-based information for its members that are currently in six surrounding cells.

Every reservation request of each call belongs to a reservation group whether it is reservation-successful or reservation-failed. When a new call arrives, CAC is first conducted. If the local cell does not have enough free bandwidth, the call is blocked; if there is any previous reservation-failed member that might be affected by accepting this call in the current reservation group in the cell, the call is blocked. Otherwise, the call is accepted. Next, bandwidth reservation is preformed in neighboring cells. The amount of bandwidth reserved is based on the bandwidth requirements of reservation-successful members in the current group, the estimated handoff probabilities of the members, and the information of the current call. A call will be a reservation-successful member if both the amount of reserved bandwidth in a group including the bandwidth requirement of this call is less than the total cell capacity,

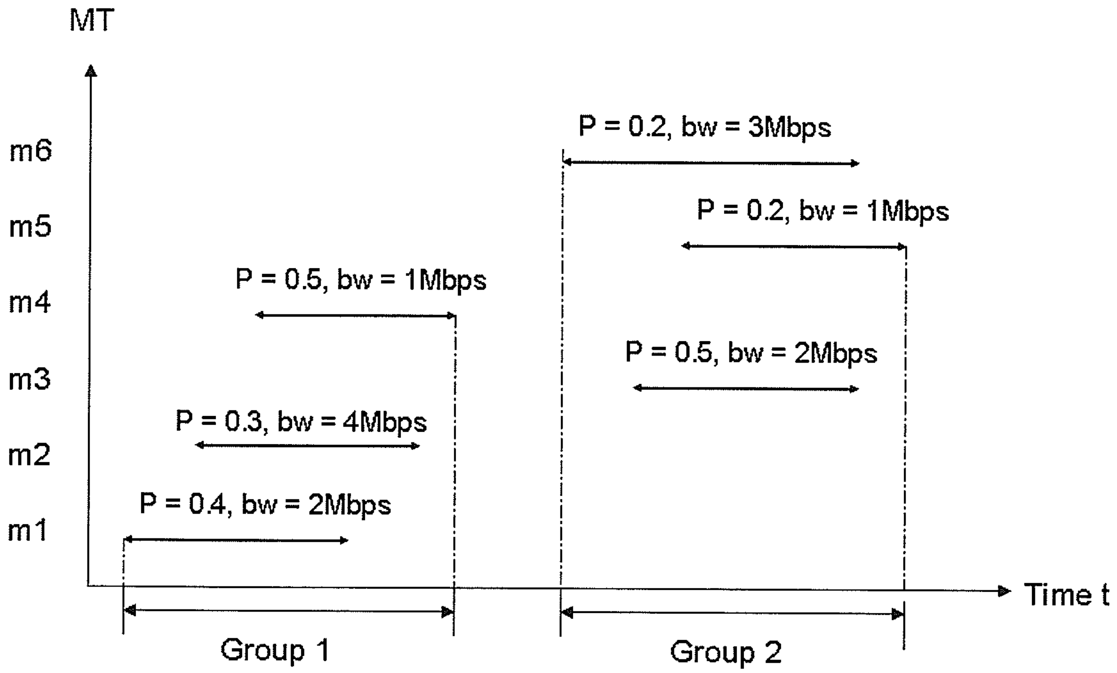

Figure 2.2: Example of grouping reservation requests

and the sum of the probabilities of reservation-successful members in the group including the probability of this call is less than 1. Assume that the cell capacity is 5Mbps. In Figure 2.2, group 1 has three reservation requests, $m1$, $m2$, and $m4$ in that order. When $m2$ joins the group, the total requested bandwidth becomes greater than the cell capacity. Thus, $m2$ becomes a reservation-failed member, and the total probability of group 1 is 0.4. When $m4$ joins group 1, the total requested bandwidth, which is 3 Mbps, is less than the cell capacity, and the total probability of group 1 is less than 1. Thus, $m4$ becomes a reservation-successful member.

When a handoff call arrives, if it is a reservation-successful call at this cell, it is accepted as long as the desired bandwidth is not greater than the free bandwidth plus the reserved bandwidth; if it is a reservation-failed handoff call, it is dropped if the desired bandwidth is greater than the free bandwidth.

This scheme also extends the expected handoff arrival time of an ongoing call to the time interval of the reservation group to which it belongs. Because of this, a reservation-successful member can arrive after its originally expected arrival time and still be accepted. This may improve the CDP performance. However, managing per-call information may significantly increase the algorithm complexity.

2.3 Rate Adaptation and Bandwidth Borrowing Techniques

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, 9, 14, 17, 23, 24] and bandwidth borrowing [5, 9, 10, 17, 21, 24]. When these techniques are included in CAC, bandwidth utilization can increase.

2.3.1 Rate Adaptation Schemes

Rate adaptation schemes are based on the observation that multimedia data may tolerate a certain degree of quality degradation when operating with a reduced amount of bandwidth. Using these schemes, in time of heavy load, bandwidth allocated to existing calls may be temporarily decreased to a minimum requirement in order to accommodate more calls. For example, in [9], when a new call arrives, if the network has enough bandwidth for this call, it is accepted at its maximum bandwidth requirement; otherwise, its minimum bandwidth requirement is allocated to this call. If the cell does not have enough bandwidth for this call, the new call will be rejected. When the network condition is favorable, the collected bandwidth from each ongoing call is quickly returned.

2.3.2 Bandwidth Borrowing Schemes

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 the load is heavy, bandwidth allocated to less bandwidth-constricted classes may be borrowed by more bandwidth-constricted classes. This may lead to better performance (e.g. lower CDP) for calls of more bandwidth-constricted classes. In this research, I will focus on the cases when all traffic classes are bandwidth-constricted and all bandwidth requirements for calls are fixed. Thus, I 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 the proposed scheme.

Chapter 3

The Cell-Based Call Admission Control Scheme

In this research, I develop an efficient cell-based CAC and bandwidth reservation scheme that aims to minimize CDP and CBP, and to maximize the cell bandwidth utilization. The proposed scheme uses cell-wide information when determining the amount of bandwidth to reserve and addresses the problems in some existing cell-based schemes. In this chapter, I first present the problems of existing CAC schemes and the proposed solution, and then describe the details of the proposed scheme.

3.1 Problems of Existing Schemes

Although user mobility prediction techniques proposed in recent research may be used to reduce the CDP by estimating the future cells of an ongoing call, it makes the CAC algorithm complex and difficult and may waste bandwidth if the mobility prediction is not accurate. When user mobility prediction is used to determine the amount of bandwidth to reserve, either an MT or a local cell keeps track of the moving history of the MT. From the observed mobile history, moving probabilities of the MT to each neighboring cell is determined, and these probabilities are used when performing reservation tests in its neighboring cells. Predicting user mobility can be complex as well as difficult and may require additional space for maintaining reservation information or recording the observed mobility history of an MT. In my thesis, I focus on cell-based schemes.

Existing cell-based CAC schemes may conduct bandwidth reservation on a per-call basis. When bandwidth reservation is conducted on a per call basis, it is likely to over-reserve bandwidth, thus these schemes may unnecessarily block many new calls by reserving a large amount of bandwidth exclusively for handoff calls even though the reservation pool in the local cell is idle. For example, in [2, 14], the amount of bandwidth reserved is determined by the product of the desired bandwidth requirements of the calls which are expected to handoff to the local cell from all six neighboring cells, and the estimated handoff probabilities. When at heavy load, these schemes may excessively reserve bandwidth due to the large number of ongoing calls in the neighboring cells.

Another problem of per-call based bandwidth reservation is that it may introduce high algorithm complexity. For example, the grouping scheme in [2] needs substantial amount of space to maintain reservation groups and their member lists. When the load is heavy, a cell is likely to have only one group because the expected time intervals of ongoing calls overlap each other. In this case, members in each individual group in the cell are all consolidated into a single group. When the local cell conducts reservation test, it has to retrieve the potentially large member list in the single group in order to determine the amount of bandwidth to reserve. I focus on cell-based schemes that do not maintain per-call information to reserve bandwidth.

Many existing schemes conduct reservation tests in neighbor cells for new calls as well as handoff calls. Compared to the case when reservation test is conducted for new calls only, this may increase the CDP when the reservation test for handoff calls fails. In my investigation, I compared reservation for both new and handoff calls, against reservation for new calls only.

In addition, since existing schemes include information from all ongoing calls in neighboring cells when determining the amount of bandwidth to reserve, they may over-reserve bandwidth. For instance, the scheme in [24] considers all ongoing calls in neighboring cells when the number of calls is used for reservation. However, since an ongoing call is likely to move to only one of six neighboring cells, existing schemes may result in very low cell utilization.

In short, the main problems of existing schemes are as follows:

(1) They may increase the CDP and CBP by excessively reserving bandwidth for handoffs since they use per-call information for reservation,

(2) They may have high time and space algorithm complexity,

(3) Their CDP can be high since they conduct reservation test for both new calls as well as handoff calls, and

(4) They may produce low cell bandwidth utilization due to over-reserved band-

width since they include all ongoing calls in neighboring cells when determining the amount of bandwidth to reserve.

The goal of this research is to address these problems in existing schemes. I developed an improved CAC and bandwidth reservation algorithm that produces good performance in terms of CDP, CBP and cell bandwidth utilization, reduces algorithm complexity, and finally, is simple to implement.

3.2 Design Decisions of the Proposed Solution

This section presents some decisions made in the design of my proposed solution. First, the amount of bandwidth reserved is not per-call based; rather, it is for a collection of calls. Thus, the reserved bandwidth is not assigned to any particular handoff calls but can be used by any handoff call.

Second, in the proposed scheme, the amount of bandwidth reserved for handoffs is determined based on the number of existing calls in the neighbors. So no per-call information is needed. Thus, the proposed scheme may be more efficient and inexpensive to implement.

Third, I investigated the option of conducting reservation for new calls only, and compared its performance against those of conducting reservation for both new and handoff calls.

Finally, the proposed scheme determines the size of reservation pool using a fraction of the total number of calls in all neighboring cells; this is based on the observation that not all calls in neighbors will next move to the same cell at the same time. This led to improved CBP and cell utilization performance. This also addressed the issue of over-reservation for handoffs in some existing schemes.

3.3 Description of the Proposed Cell-Based Scheme

I considered a two-dimensional mobile network with a cellular infrastructure as shown in Figure 3.1. Each cell is surrounded by six neighboring cells. I assumed 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, and bandwidth reservation. It is assumed 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. I also assumed that each MT is equipped with Global Positioning Sstem (GPS) which can track the moving speed and moving direction of an MT in real-time. This information can be conveyed to the base station at the local cell, which can in turn determine which neighbor cells to contact for bandwidth reservation purposes based on this information. In this study, soft handoff scenarios [1, 12] in which an MT may belong to more than one BS at the same time, are not considered.

When an 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 bits-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

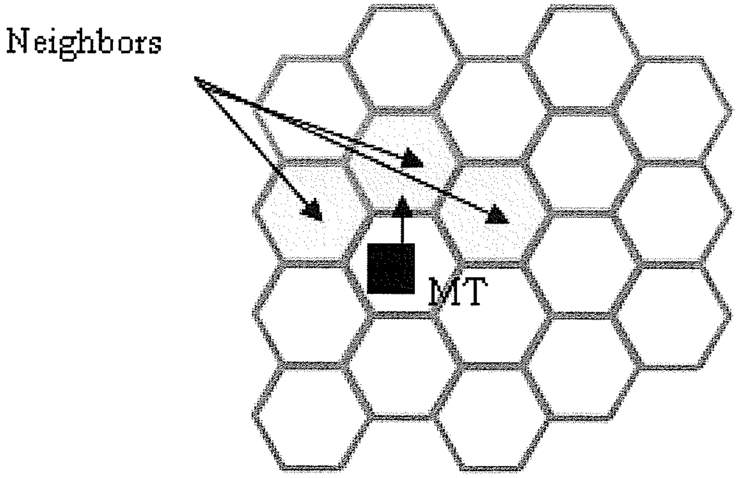

Figure 3.1: Cellular network topology

Figure 3.1, 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. If an arriving call is a handoff call, an admission test is first performed in the local cell. Depending on whether the reservation is conducted for both new and handoff calls, or for new calls only, there are two variants in my proposed scheme: P1 and P2. In P1, all handoff calls may invoke reservation tests in neighboring cells. 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 an MT leaves a cell, reserved bandwidth is released in selected neighbors. I next describe the admission test, the bandwidth reservation, and the bandwidth release procedures in sequence.

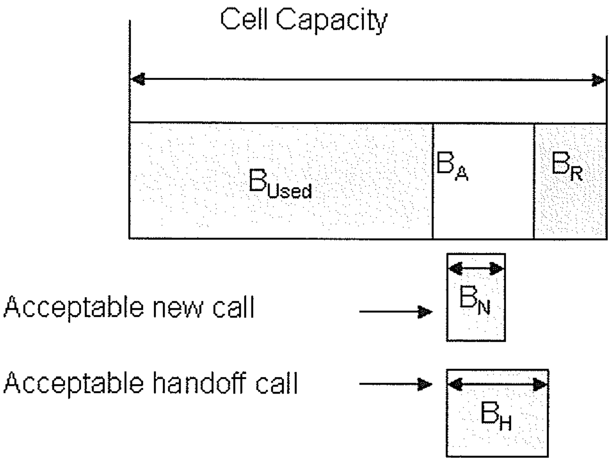

Figure 3.2: Logical view of cell bandwidth partitions

3.3.1 Admission Test

The admission test is conducted differently for new calls and handoff calls. When a new call arrives, CAC first checks the amount of free bandwidth, which is the cell capacity minus the amount of used and reserved bandwidth. A new call is accepted if there is enough free bandwidth for the new call, and the reservation is successful in selected neighboring cells. A handoff call is accepted if the reserved bandwidth plus the free bandwidth is greater than the desired bandwidth, and under certain circumstances, if the reservation is successful in selected neighboring cells.

Let C denote the total bandwidth of a cell. I partition the total bandwidth into three logical portions: $Bused$, Ba, and Br as shown in Figure 3.2. $Bused$ 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 algorithm of admission test for new calls in P1 is given in Algorithm 1. The algorithm of admission test for handoff calls in P1 is given in Algorithm 2.

```
1 if $bw \leq (C - Br - Bused)$ then
2     select a set of neighboring cells;
3     reservation test in these neighbors (*a);
4     if successful in all then
5         reservation in these cells (*b);
6         $Bused = Bused + bw$ // $Br$ does not change;
7         increase the number of calls in the current cell;
8     else block this new call;
9 else block this new call;
```

Algorithm 1: Admission test for a new call in P1

Upon arrival of a new call, the algorithm compares its bandwidth requirement, bw, with the available bandwidth, $C - Br - Bused$ (line 1 in Algorithm 1). 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 1 in Algorothm 2). 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 (Algorithm 1). For handoff calls, if the cell has enough bandwidth (line 1 in Algorothm 2), a handoff probability p is calculated based on the number of handoffs that the call has experienced. With probability p, reservation tests and subsequent reserva-

```
1  if $bw \leq (C - Bused)$ then
2      Determine handoff probability $p$;
3      With probability $p$;
4      select a set of neighboring cells;
5      reservation test in these neighboring cells (*a);
6      if successful in all then
7          reservation in these cells (*b);
8          $Ba = C - Bused - Br$, $Bused = Bused + bw$;
9          if $bw > Ba$ then $Br = Br + Ba - bw$;
10         increase the number of calls in the current cell;
11     else drop this handoff call;
12     With probability (1-$p$);
13     $Ba = C - Bused - Br$, $Bused = Bused + bw$;
14     if $bw > Ba$ then $Br = Br + Ba - bw$;
15     increase the number of calls in the current cell;
16 else drop this handoff call;
```

Algorithm 2: Admission test for a handoff call in P1

tion are performed in neighboring cells (lines 2–11 in Algorothm 2). With probability $(1 - p)$, the handoff call is accepted without incurring any reservation in neighbors (lines 12–15 in Algorothm 2). The handoff probability signifies the probability that the call will terminate in the local cell. I assumed that a call that has experienced more handoffs is more likely to terminate. The formula I used for calculating p is

$p = \frac{1}{1+Nh}$, where Nh is the number of handoffs the call has experienced.

In P1, because all handoff calls may invoke reservation tests 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, I removed the reservation test in neighboring cells for handoff calls. The admission test for P2 is shown in Algorithm 3; only the changed portion from P1 is included. 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;
if new call then  see Algorithm 1;
else
    if $bw \leq C - Bused$ then
        $Ba = C - Bused - Br$ // get available bandwidth;
        $Bused = Bused + bw$;
        if $bw > Ba$ then $Br = Br + Ba - bw$;
        increase the number of calls in the current cell;
    else drop this handoff call;
```

Algorithm 3: Segment of admission test for P2

In Algorithm 1 (line 3) and Algorithm 2 (line 5), a set of neighbors are selected for reservation. This set can be determined based on simple MT information such as velocity and moving direction. Note that differ from mobility-based schemes, my scheme does not perform complex mobility predictions, rather uses much simpler method to determine neighboring cells for bandwidth reservation. In the experiments, I defined 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.

3.3.2 Reservation Test and Bandwidth Reservation

In this subsection, I describe the reservation test and the possible subsequent bandwidth reservation that is invoked by the admission tests presented in the last subsection. In P1, same as the case of a new call, a reservation test is next conducted in selected neighboring cells for a handoff call. If both tests are successful, the handoff call is accepted and the bandwidth is reserved in these neighbors. In P2, the reservation test is conducted only for new calls; thus, it is not conducted in neighboring cells for handoff calls. 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. The reservation test uses the total number of ongoing calls in all neighbors plus the current call to determine the amount of bandwidth to reserve. If there is enough free bandwidth, the test is passed; otherwise, the test is unsuccessful. When all reservation tests in selected neighboring cells are successful, bandwidth is reserved in these cells. Note that requiring that all reservation tests be successful might be somewhat conservative. Future investigation may be carried out to relax this to some degree.

The invocation of these two procedures are indicated by (*a) and (*b) in Algorithms 1 and 2 respectively. The reservation test for both P1 and P2 is shown in

Algorithm 4. The corresponding bandwidth reservation procedure is very simple, and is shown in Algorithm 5.

```
1  // (*a) RESERVATION TEST IN SELECTED NEIGHBOR;
2  get total number of calls, N, in all neighbors;
3  determine amount of bandwidth $r\_bw$ using $N + 1$;
4  if $r\_bw \leq C - Bused$ then return SUCCESS;
5  else
6      determine amount of bandwidth $r\_bw'$ using $N$;
7      if $r\_bw' > C - Bused$ then
8          $Br = C - Bused$ // $Ba = 0$;
9      else $Br = r\_bw'$;
10     return FAIL;
11 end
```

Algorithm 4: Reservation test in selected neighbors (P1 and P2)

```
(*b) RESERVATION IN SELECTED NEIGHBORS;
continuing the algorithm in Algorithm 4;
$Br = r\_bw$ // get available bandwidth;
```

Algorithm 5: Reservation in selected neighbors (P1 and P2)

The reservation test in Algorithm 4 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 4). Otherwise, the test is unsuccessful (line 10). 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 6–9). 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 4 of Algorithm 4 is evaluated to true). The algorithm simply assigns r_bw to Br.

Both the reservation test and the actual bandwidth reservation depend on a function to determine a proper amount of bandwidth to reserve. In the proposed scheme, this amount is determined based on the number of on-going calls in each selected neighboring cell (see lines 3 and 6 in Algorithm 4). I defer the description of how I determine this amount to Chapter 4.

3.3.3 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 Algorithm 6. Essentially, the algorithm re-adjusts the amount of bandwidth to reserve based on the current total number of calls in all neighbors.

This concludes the description of my scheme.

```
// BANDWIDTH RELEASE IN SELECTED NEIGHBORS;
get total number of calls, $N$, in all neighbors;
determine amount of bandwidth $r\_bw$ using $N$;
if $r\_bw > (C - Bused)$ then
    $Br = C - Bused$ // $Ba = 0$;
else $Br = r\_bw$;
```

Algorithm 6: Reservation release in each selected neighbor (P1 and P2)

Chapter 4

Simulation Model and Experimental Results

In this chapter, a simulation model is developed to evaluate the performance of the proposed cell-based CAC scheme, and a simple analytical model is developed to verify the correctness of the simulation model. I first describe other schemes that I implemented for performance evaluation of the proposed scheme. The network model, the traffic model, the analytic model, and the performance measures that I used are next presented in sequence.

Then, I describe the experiments that I conducted and the amount of bandwidth reserved in the experiments. Using the simulation model, simulation experiments were carried out to evaluate the performance of the proposed scheme. Each experiment consisted of six replications; the sample mean and the 99% confidence interval were computed and reported for each experiment. The performance results are reported at the end.

4.1 Implemented Schemes

Besides P1 and P2, four other schemes were implemented in my simulation model. These are OKS [24], dynamic-grouping scheme [2], static reservation scheme, and no reservation.

4.1.1 OKS Scheme

The OKS scheme is very similar to the proposed scheme except that

(1) bandwidth reservation is performed in all neighbors,

(2) the amount of bandwidth reserved is different from the proposed scheme, this will be detailed in Section 4.4.5, and

(3) reservation is always conducted for handoff calls.

The pseudo code description of OKS scheme is given in Algorithm 7.

4.1.2 Dynamic-Grouping Scheme

As described in Section 2.2.2, the dynamic-grouping scheme performs bandwidth reservation based on the information of the current group in each cell. The acceptance of a handoff call is determined by the expected time interval of the group where the call belongs to, rather than the arrival time of the call. A new call is accepted if enough free bandwidth is available in the local cell and if there is no reservation-failed member in the current group. A reservation-successful handoff call is accepted as long as there is available bandwidth enough to the handoff call. If its reservation request

```
// CALL ADMISSION TEST FOR OKS;
if new call then
    if $bw \leq (C - Br - Bused)$ then
        reservation test in all neighbors;
        if successful in all then
            reservation in neighbors;
            $Bused = Bused + bw$ // $Br$ does not change;
            increase the number of calls in the current cell;
        else block this new call;
    else block this new call;
else
    if $bw \leq (C - Bused)$ then
        reservation test in all neighbors;
        if successful in all then
            reservation in neighbors;
            $Ba = C - Bused - Br, Bused = Bused + bw$;
            if $bw > Ba$ then $Br = Br + Ba - bw$;
            increase the number of calls in the current cell;
        else handoff drop;
    else handoff drop;
end
```

Algorithm 7: OKS scheme implemented

```
// CALL ADMISSION TEST FOR A NEW CALL X IN DYNAMIC-GROUPING SCHEME
if $bw \leq C - Br - Bused$ then
    while there exists a reservation-failed member Y in the current reservation group, coming from neighboring cell i to the current cell j do
        if $P_{xj} \geq P_{\alpha}$ and $(bw + bw_Y > C - Br - Bused)$ then block this new call;
    end
    if this call is not blocked then
        $Bused = Bused + bw$;
        bandwidth reservation tests for X in all neighbors;
else block this new call;
```

Algorithm 8: Algorithms for handling new calls in Dynamic-grouping scheme

to a neighboring cell is rejected, the handoff call will be entered to the reservation group in the neighboring cell as a reservation-failed member. If a handoff call is a reservation-failed member, the CAC at the local cell accepts the handoff call only if enough free bandwidth is available for the handoff call. This is similar to the case of a new call. The pseudo code description of the dynamic-grouping scheme is given in Algorithms 8, 9, and 10. Note that P_{xj} is the moving probability of MT X from neighboring cells to a cell j, and P_{α} is the given threshold for the moving probability to the current cell j.

In Algorithm 10, $P_{g,n}$ is the sum of moving probability and $BW_{g,n}$ is the sum of required bandwidth of reservation-successful members in group g at cell n. The

```
// CALL ADMISSION TEST FOR A HANDOFF CALL X IN DYNAMIC-GROUPING SCHEME
if $X$ is a reservation-successful member in the current group in the current cell $j$ then
    if $bw > C - Bused$ then drop this handoff call X;
    else
        $Bused = Bused + bw$;
        bandwidth reservation tests for X in all neighbors;
        delete the reservation request of X from the current group in the current cell $j$;
        adjust the amount of bandwidth reserved in the current group;
else
    // X is a reservation-failed member or not in the current group in the current cell $j$
    if $bw > C - Bused - Br$ then drop X;
    else
        $Bused = Bused + bw$;
        bandwidth reservation tests for X in all neighbors;
        search for group $g$ to which X belongs in the current cell $j$;
        if $g \neq currentgroup$ and X is reservation-successful member in $g$ then adjust the amount of bandwidth reserved in group $g$;
```

Algorithm 9: Algorithms for handling handoff calls in Dynamic-grouping scheme

```
// BANDWIDTH RESERVATION TEST IN NEIGHBORING CELLS
Search for a group $g$ in a neighboring cell $n$ to which an MT X belongs
if $P_{g,n} \leq 1$ and $BW_{g,n} \leq C$ //cell capacity then
    X becomes a reservation-successful member in group $g$
    Update the expected time interval of group $g$
else X becomes a reservation-failed member in group $g$;
```

Algorithm 10: Reservation test in Dynamic-grouping scheme

amount of bandwidth reserved is determined by either the biggest amount of bandwidth of a reservation-successful member or the product of the moving probabilities of reservation-successful members and their bandwidth in the group.

4.1.3 Static Reservation Scheme

Static reservation scheme and no reservation scheme are two baseline schemes. In the simulation model, the amount of reserved bandwidth in the static scheme is specified as a percentage α of the total cell bandwidth, where α is an input parameter. Algorithm 11 contains the pseudo code description of the static scheme. Note that bw in Algorithm 11 is the bandwidth requirement of the incoming or outgoing call.

4.1.4 No Reservation Scheme

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

$(Bused = Bused - bw)$.

```
// CAC for STATIC RESERVATION SCHEME ;
if new call then
    if $bw \leq C - Bused - Br$ then $Bused = Bused + bw$;
    else block this new call;
else
    if $bw \leq C - Bused$ then
        $Bused = Bused + bw$
        if $C - Bused \leq \alpha C$ then $Br = C - Bused$;
    else drop this handoff call;
end
// BANDWIDTH RELEASE IN STATIC RESERVATION SCHEME ;
$Bused = Bused - bw$;
if $C - Bused > \alpha C$ then $Br = \alpha C$;
else $Br = C - Bused$;
```

Algorithm 11: Algorithms for Static reservation scheme

4.2 Development of a Performance Model

To evaluate the performance of the proposed scheme, a discrete event simulation model written in C was used. A simple analytic model is presented to verify the correctness of my simulation.

4.2.1 Network Model

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

4.2.2 Traffic Model

I assumed that all calls arrive at the network from a Poisson process at a rate of 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 [2, 24]. 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 dividing cell diameter by the velocity of the call.

Three mobility levels, low, medium, and high, are defined in the proposed model and used in the experiments as an input parameter. 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 4.1. The low mobility level is used to model an urban shopping area. All

Table 4.1: Three mobility levels in the simulation 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 in moving direction
Cell diameter (km)	0.2	1	1
Selected neighbors for reservation	All six neighbors	Three neighbors in moving direction	Three neighbors in moving direction

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. For the experiments, I used the parameters and values from existing studies on telephone call durations [2] and streaming multimedia durations [18]. 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 in 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.

In Table 4.1, 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).

4.2.3 Analytic Model

In order to verify the correctness of my simulation model, bandwidth utilization from an analytic model is calculated. It is compared with bandwidth utilization results obtained from simulation. I assume that voice calls and video calls arrive to a cell at rates of λ_{voice} calls/second and λ_{video} calls/second, respectively. Let D_{voice} and D_{video} respectively denote the mean call durations for voice and video calls. Let B_{voice} denote the mean bandwidth requirement of voice calls and B_{video} denote the mean bandwidth requirement of video calls. Let the cell capacity be C. When traffic is light, i.e., when there is no call blocking or call dropping, the cell bandwidth utilization can be estimated by

$$U = \frac{\lambda_{voice} D_{voice} B_{voice} + \lambda_{video} D_{video} B_{video}}{C} \tag{4.1}$$

4.3 Performance Measures

Both system-wide and cell-wide performance results were obtained in the experiments. Due to the results being similar, I only report the aggregated system-wide performance in this thesis. I used four performance measures of interest. These are:

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

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

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

$$U = \frac{\sum_i T_i \times Bused}{T \times C} \tag{4.2}$$

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. C denotes the total capacity of the cell. The aggregated utilization is defined to be the arithmetic mean of utilization of all cells.

(4) Total system award, Ω. This is a comprehensive score and is defined in Equation (4.3). 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, I chose 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.

$$\Omega = a \times CDP + b \times CBP + c \times (1 - U) \tag{4.3}$$

4.4 Simulation Experiments and the Amount of Bandwidth Reserved

There are three major input factors to the experiments. The first one is the reservation scheme. There are six schemes: P1, P2, OKS, Dynamic-grouping reservation, static reservation scheme, and the no reservation scheme. For static reservation, a value of 10% is used in most experiments for α, the percentage of bandwidth reserved. I also conducted the experiments with different α. 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

$$L = (0.5 \times bw_{voice} + 0.5 \times bw_{video}) \frac{\lambda_0 \mu^{-1}}{C} \tag{4.4}$$

The first term in Equation (4.4) computes the average bandwidth requirement per call in Kbps. λ_0 denotes the average call arrival rate at each cell. In my model, $\lambda_0 = \lambda/100$. μ^{-1} is the average call duration, and C is the cell bandwidth. In the experiments, six levels of L, ranging from 0.5 to 3 in steps of 0.5, were used. For each mobility level, the performance on CDP, CBP, and U is compared among various schemes as the level of load is increased. Each simulation run has 50,000 seconds of run-time in order to get steady-state performance.

The amount of bandwidth that I used in bandwidth reservation for both OKS and the proposed scheme is listed in Table 4.2. 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 [24]. 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 the proposed scheme, only one sixth of the amount in OKS is reserved (see the last column in Table 4.2).

Table 4.2: Reserved bandwidth based on the number of calls

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

4.4.1 Simulation Model Verification

Equation 4.1 in Section 4.2.3 is used to verify my simulation model. The cell bandwidth utilization using simulation was collected and compared with the one calculated analytically. Since each class has the same arrival rate, $\lambda_{video} = \lambda_{voice} = \frac{1}{2}\lambda$. Thus,

$$U = \frac{0.5\lambda D_{voice} B_{voice} + 0.5\lambda D_{video} B_{video}}{C} \tag{4.5}$$

Table 4.3 presents a numerical comparison of the cell bandwidth utilization obtained from the analytic model and the simulation model. New call blocking or handoff call dropping occurs when the offered load $L \geq 0.4$ in the simulation model. The comparison shows that the results from the two models match well.

Table 4.3: Comparison of analytical and simulation results

Offered Load	U of Analytic Model	U of Simulation Model
0.1	0.103532	0.106422
0.2	0.206967	0.200472
0.3	0.309044	0.294652
0.4	0.411897	0.393208
0.5	0.505629	0.481636

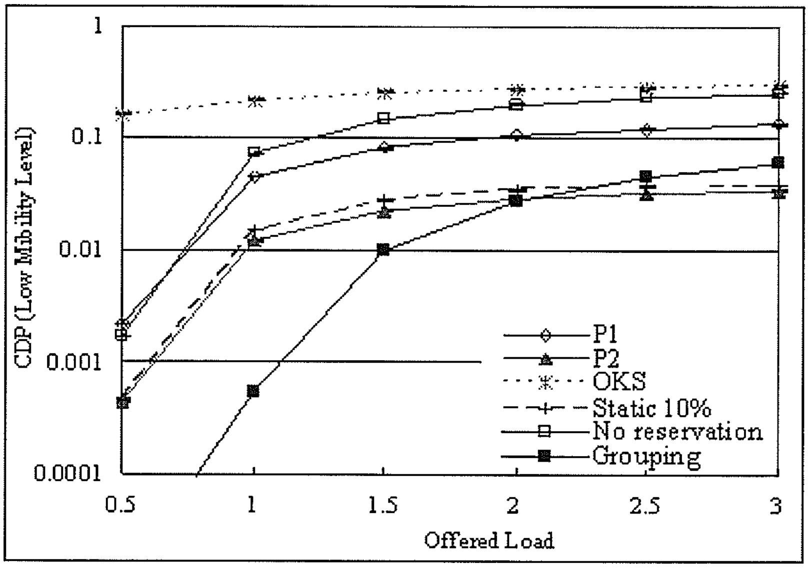

Figure 4.1: CDP for low mobility level case

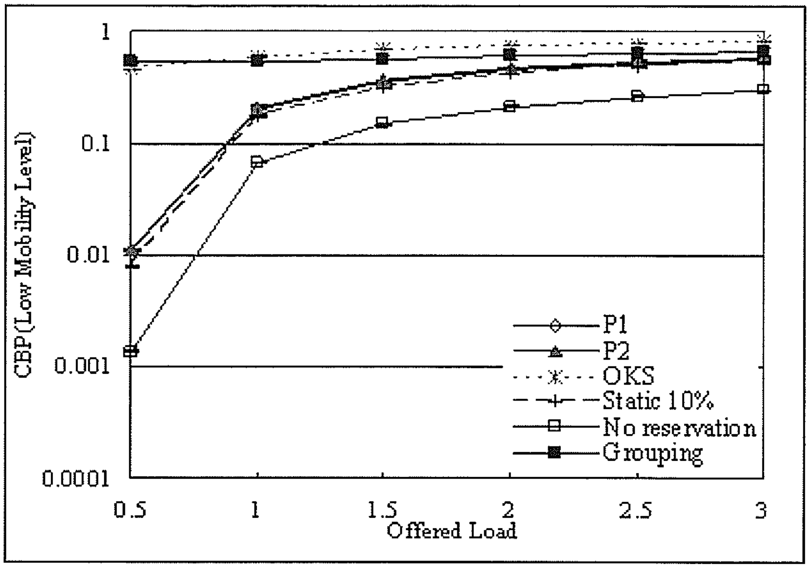

Figure 4.2: CBP for low mobility level case

4.4.2 Results on CDP, CBP, and U

In Figures 4.1, 4.2 and 4.3, I plot the results for the low mobility level case. The three figures 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 six schemes experimented, the grouping scheme achieves the lowest CDP when L is less than 2, and P2 achieves the lowest CDP when $L \geq 2$; when $L = 3$, the CDP is 3.4% for P2, 3.8% for static scheme, 5.8% for the grouping scheme, 13.2% for P1, and higher than 20% for the other 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.

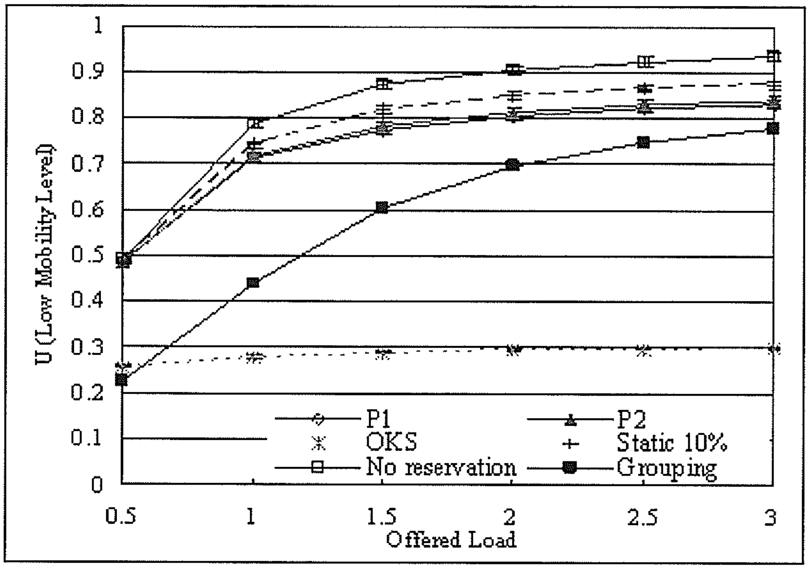

Figure 4.3: Bandwidth utilization for low mobility level case

Results for the medium mobility level case are plotted in Figures 4.4, 4.5, and 4.6 respectively. Figures 4.7, 4.8, and 4.9 plot the results for the high mobility level case. 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%. I conclude that the variant P2 of the proposed scheme achieves the best performance in terms of CDP when L becomes greater and can achieve comparable performance with other reservation schemes in terms of CBP and U.

4.4.3 Results on Total System Award

In order to gain a view on the overall performance of each scheme, I also obtained the results on the total system award, Ω. I selected the set of weights (0.8, 0.1, 0.1) for the set of coefficients (a, b, c) in Equation (4.4). This set places heavy weight on

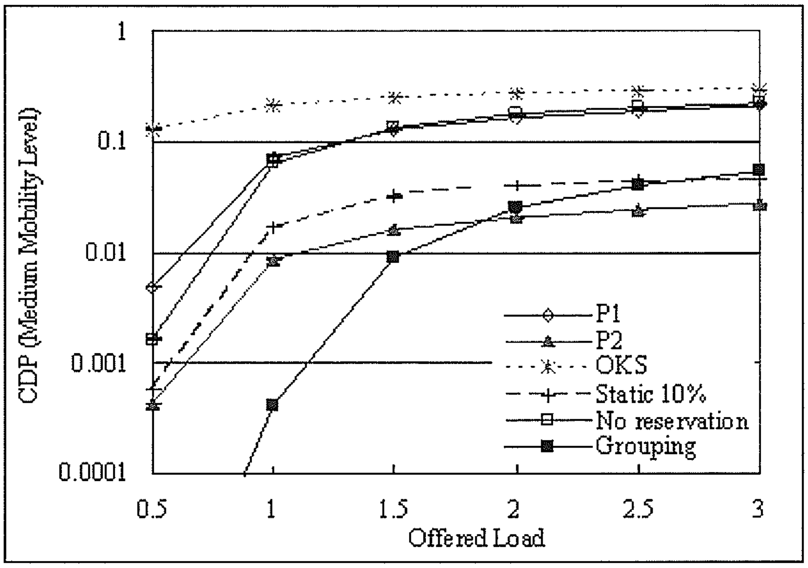

Figure 4.4: CDP for medium mobility level case

CDP and light weights on CBP and U. The results are plotted in Figures 4.10, 4.11, and 4.12 for the low, medium, and high mobility levels, respectively.

It can be observed in Figure 4.10 that both P2 and the static scheme achieve the best performance for all load levels and all mobility levels. In Figure 4.11 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. In Figure 4.12 between P2 and the static scheme, at low and medium mobility levels, their performance is very close; at the high mobility level, P2 has slightly better performance and the performance lead is slightly larger when the level of load in increased. I conclude that in terms of total system award, the proposed scheme P2, along with the static scheme, achieve the best overall performance among all other schemes experimentally compared. The performance gain of P2 is more clearly shown when the load is heavier

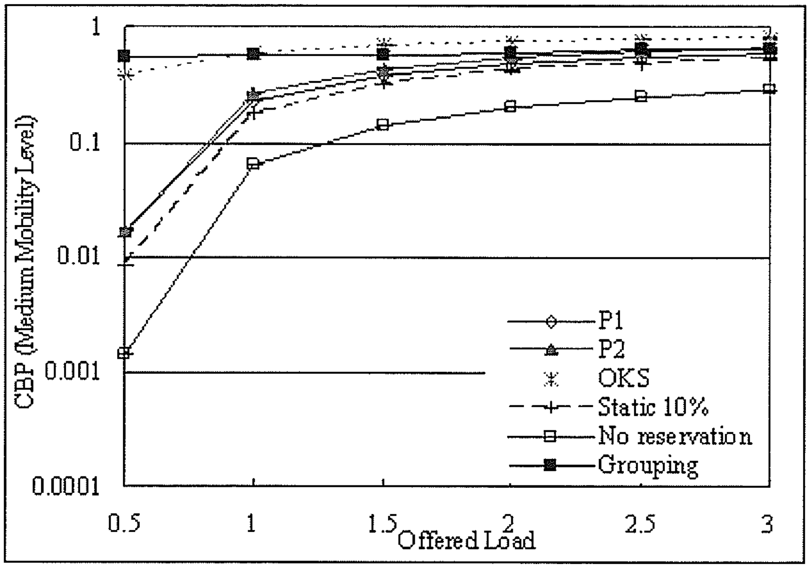

Figure 4.5: CBP for medium mobility level case

and the mobility level is higher.

4.4.4 Comparison of P2 and Dynamic Grouping Scheme

The dynamic-grouping scheme improved the CDP in all three mobility models when the network traffic was low. This is clearly shown in Figures 4.1,4.4, and 4.7 when the offered load is less than 2. When the traffic is heavy, P2 performs best. In contrast, the CBP of the dynamic grouping scheme is very high. In terms of bandwidth utilization, the performance of the dynamic grouping scheme is poor when the offered load is less than 1 (see Figures 4.3, 4.6, and 4.9). This means that the dynamic-grouping scheme blocks many new calls to achieve better CDP in the low offered load condition. On the other hand, the performance of P2 shows comparatively low CBP and high bandwidth utilization at both low and high offered

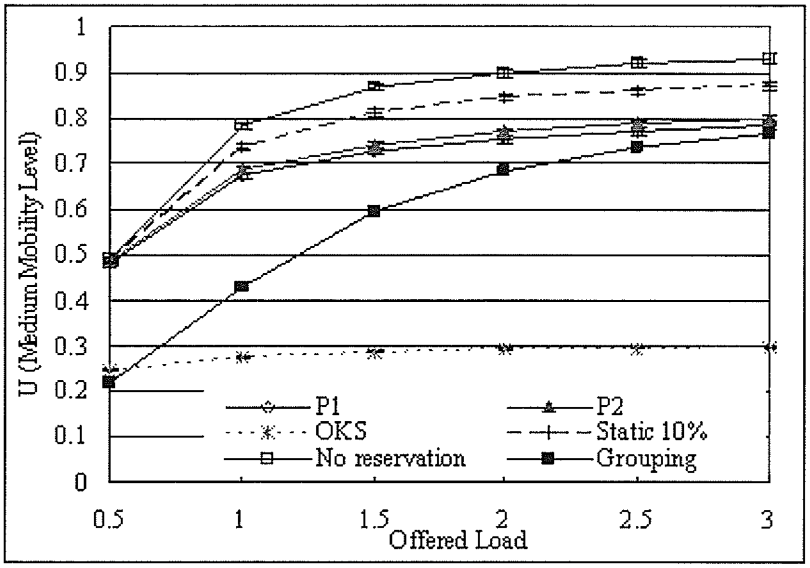

Figure 4.6: Bandwidth utilization for medium mobility level case

load conditions. The results on total system award in Figures 4.10, 4.11, and 4.12 clearly show that the proposed scheme P2 achieves better performance compared to the dynamic grouping scheme.

4.4.5 Selecting the Amount of Bandwidth to Reserve

The 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, I take an experimental approach to locating the optimal. From the results in the last two subsections, I found that the top performers among reservation schemes are P2 and the static scheme. To find the optimal amount of bandwidth to reserve, I vary the amount of reserved bandwidth, and plot the total system award Ω versus the amount

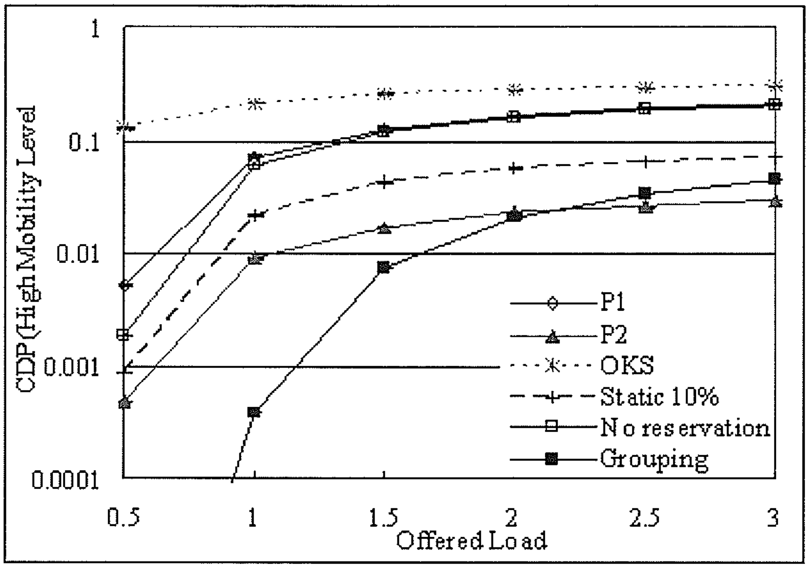

Figure 4.7: CDP for high mobility level case

of bandwidth reserved for the medium mobility level. The weight set (0.6, 0.2, 0.2) was 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 4.13 and 4.14, 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 4.2 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. I 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

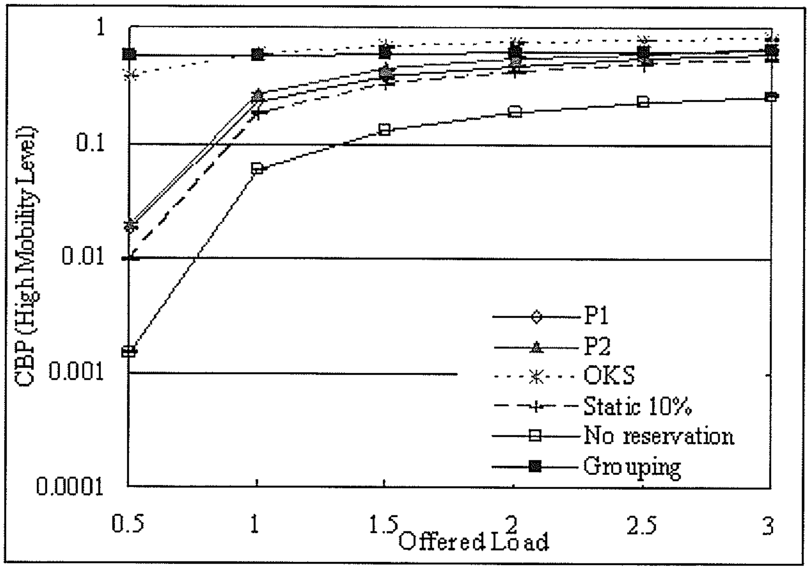

Figure 4.8: CBP for high mobility level case

with my 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.

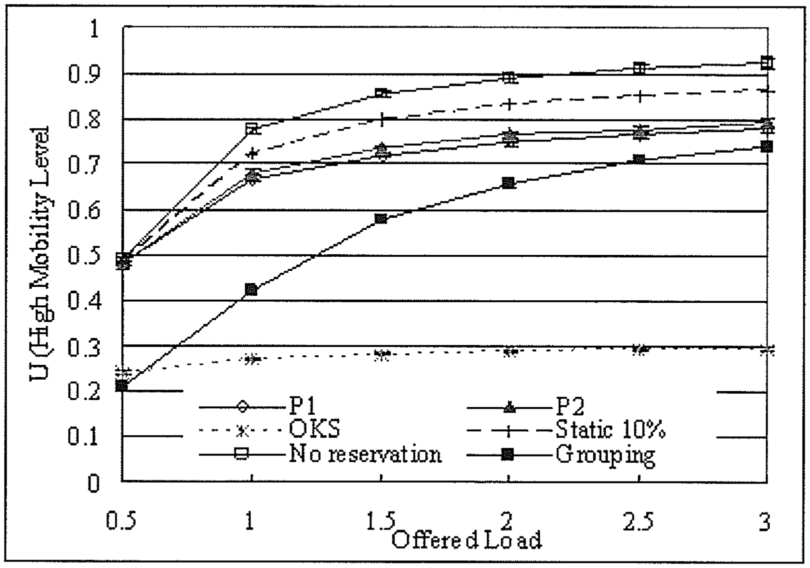

Figure 4.9: Bandwidth utilization for high mobility level case

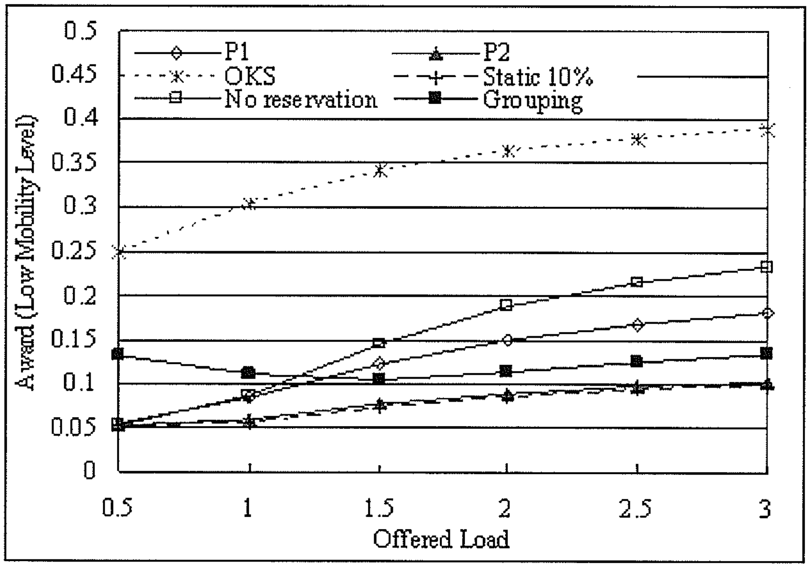

Figure 4.10: Total system award for low mobility level case (weight 0.8, 0.1, 0.1)

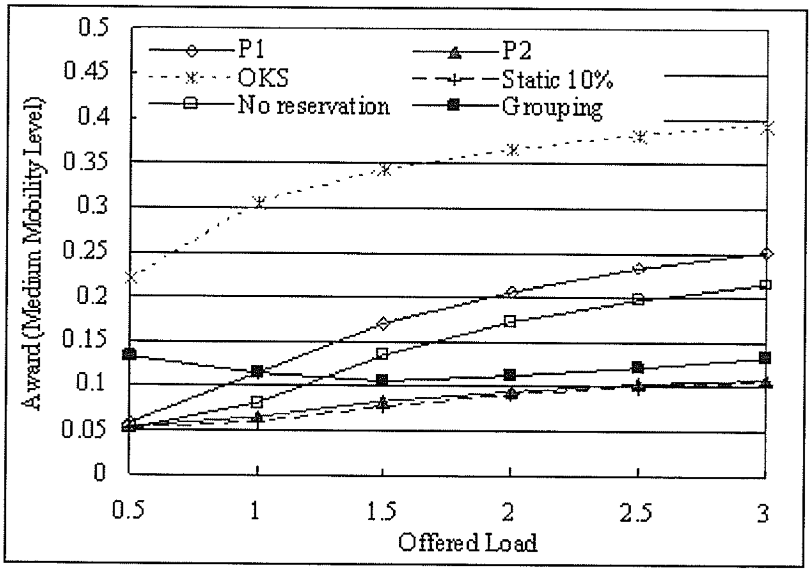

Figure 4.11: Total system award for medium mobility level case (weight 0.8, 0.1, 0.1)

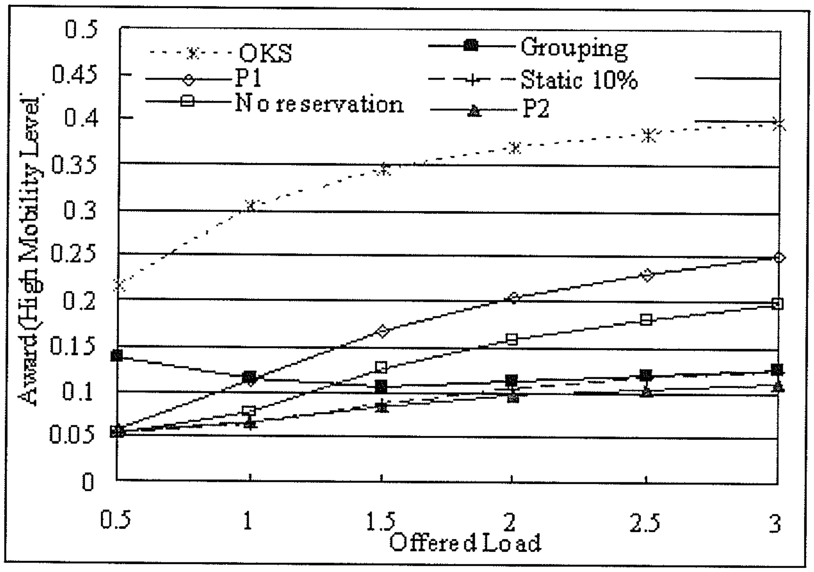

Figure 4.12: Total system award for high mobility level case (weight 0.8, 0.1, 0.1)

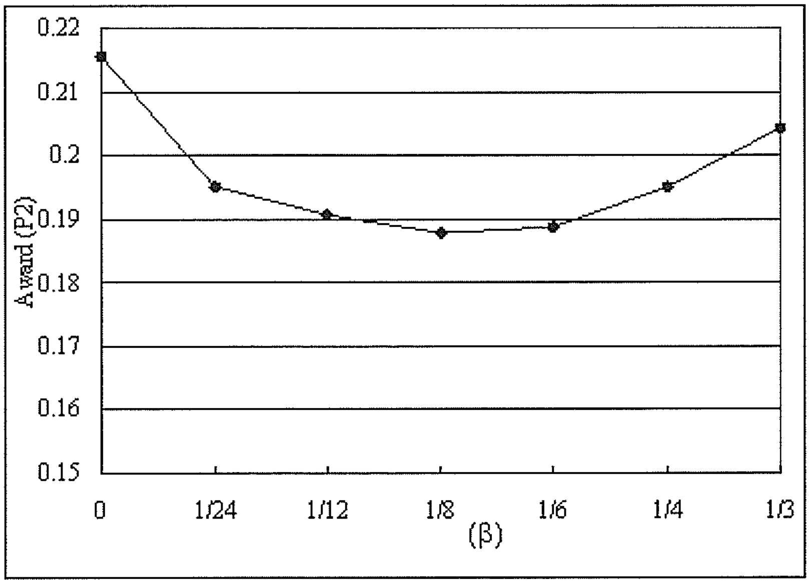

Figure 4.13: Optimal total system award (P2)

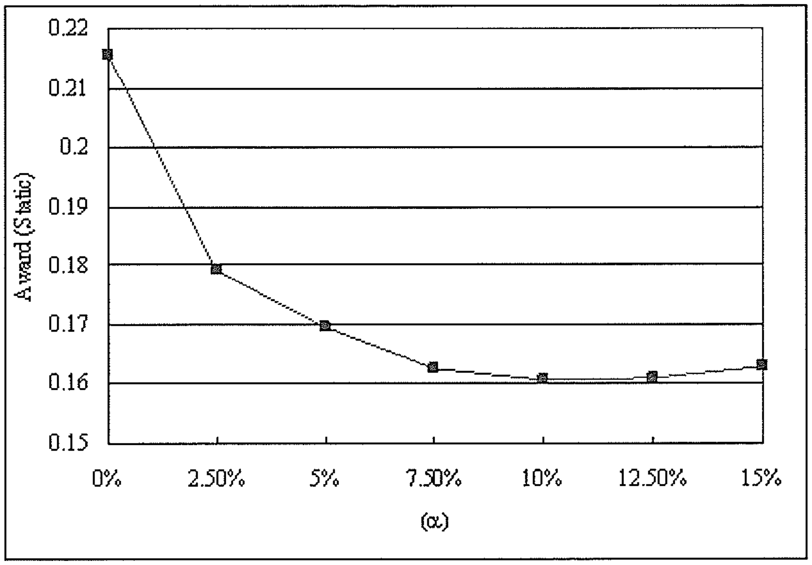

Figure 4.14: Optimal total system award (Static scheme)

Chapter 5

Conclusions

CAC and bandwidth reservation are among the key mechanisms in providing QoS support in wireless cellular networks. Many existing schemes use the history of user mobility so that they may predict the next visiting cell of a mobile. However, calculating user-mobility pattern can be complex and expensive in terms of implementation. Some other schemes have been proposed to use cell-wide information. Since they consider all neighboring cells as a next visiting cell of a call, often bandwidth is wasted, thus ineffectively utilizing cell bandwidth. In this thesis, I propose a cell-based scheme, in which 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.

I 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 thesis, I defined a new performance metric, called the total system award that represents the overall performance of a CAC scheme.

I evaluated the performance of my scheme through simulation under various load levels and user mobility conditions. The performance measures that I used include CDP, CBP, U, as well as the total system award. 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. The results show that, when compared with a number of existing bandwidth reservation schemes as well as with no reservation scheme, the proposed scheme achieves lower handoff dropping probability, comparable bandwidth utilization, and superior total system award. The experiments show that the proposed scheme, namely P2, achieves the best overall performance. The performance gain of the proposed scheme is more clearly shown when the load is heavier and the mobility level is higher.

5.1 Contributions

The main contribution of this thesis is the development of a cell-based call admission control and bandwidth reservation scheme that aims to minimize the handoff dropping probability and the new call blocking probability, while maximizing cell bandwidth utilization. The amount of bandwidth reserved is determined by cell-wide information such as the total number of calls in neighboring cells. Such a scheme may achieve comparable or superior performance to sophisticated mobility-estimation based schemes, yet may be simpler to implement. The discrete event simulation model that includes a number of existing and baseline schemes can be used to extend this research to include other schemes or special techniques such as rate adaptation or bandwidth borrowing.

5.2 Future Work

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. Time delay scenarios can also be considered when conducting admission control for new calls. For example, CAC can admit a new call as long as free bandwidth is available and the current CDP is lower than a given threshold. Even though some reservation tests in neighboring cells may fail at this new call arrival, CAC can retry the reservation tests to neighboring cells within the call duration in this cell. This way, CBP can be reduced, and thus cell bandwidth utilization can be improved. Adopting this approach, the threshold for keeping CDP low should be carefully considered; CDP can increase if the new calls accepted can not obtain bandwidth reservation during their cell residence time.

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