A Differential Bandwidth Reservation Policy for Multimedia Wireless Networks

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Abstract

Provisioning of seamless communication for mobile terminal (MT) handoffs as well as guaranteeing a certain level of Quality-of-Service(QoS) to on-going connections and new connections are critical issues in multimedia wireless networks. In this paper, we present a Differential Bandwidth Reservation(DBR) algorithm that can meet these requirements. For bandwidth reservation, the DBR scheme examines a sector of cells, which are located along the way to which the MT might move. The sector of cells are further divided into two regions depending on whether they have an immediate impact on the handoff or not. Two different bandwidth reservation policies are applied to cells in the two regions to optimize the connection dropping rate while maximizing the connection acceptance rate. Two possible MT movements are analyzed using the DBR mechanism. In the first case, no knowledge of the user's moving path is assumed to be available, while in the second case, prior knowledge of user profile is used in bandwidth reservation, and it is called User Profile-based DBR (UPDBR) algorithm.

Simulation results indicate that the DBR algorithm is more adaptable to optimize the system performance in terms of call dropping rate compared to prior schemes. The UPDBR scheme can exploit the MT's moving path history for better bandwidth utilization as well as reduction in the number of communication messages compared to the DBR scheme. The overall results show that the proposed schemes can not only provide better performance, but also exploit the current state of the system in optimizing different performance parameters.

1 Introduction

With the increasing use of wireless networks as a ubiquitous communication infrastructure, provision of seamless communication as well as Quality-of-Service(QoS) guarantees to on-going and new connections are critical issues in current wireless network technologies. Since users are expected to move around during communication sessions, one of the most important QoS factors is related to handoff, which is a mechanism of transferring an on-going connection from the current cell to the next cell to which a mobile terminal (MT) moves. A handoff, however, could fail due to unavailability of sufficient bandwidth in the destination cell. As the individual cell size gradually shrinks to accommodate increasing number of MTs with limited frequency spectrum, the probability of connection handoffs, and hence being dropped due to insufficient bandwidth during the lifetime of a connection could be high. One way to reduce the connection dropping rate (CDR) is to reserve some bandwidth solely for handoff use. However, the connection blocking rate (CBR) of new connections may increase due to such bandwidth reservations. Hence, reduction of CBR and CDR are conflicting requirements, and optimization of both is admittedly extremely complex.

In light of this, dropping handoff of on-going connections is considered more objectionable than blocking a new connection. Most admission control policies therefore attempt to provide an acceptable CDR. Early bandwidth reservation schemes [7, 11] were based on handoff prioritization; that is, each cell reserves a fixed bandwidth or dynamically adjustable amount of bandwidth exclusively for handoffs. Other prioritizing schemes [6, 15] either allow handoffs to be queued or allow new connections to be queued until enough bandwidth is available in the cell.

Instead of only considering the current cell where the new connection is initiated, recent approaches [1, 8, 10] consider the status of a number of cells, which are located around or along the way to which the MT might move, and then make a connection admission decision based on the agreement among a subset of cells or all cells. For example, Naghshineh et al [10] suggested a distributed admission control policy where the current cell and all adjacent cells are considered to decide whether a new connection is accepted or not. The shadow cluster concept was introduced by Levine et al [8] where a set of cells located around an active MT participate in bandwidth reservation for handoffs. Aljadhai et al [1] defined a Most Likely Cluster(MLC), which is a set of cells to which an MT is likely to move with

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a higher probability during its lifetime. The shape of the MLC and the number of cells in the MLC are determined based on the moving speed and direction of the MT. The Predictive Timed QoS guarantees (PT_QoS) approach applies the concept of MLC, and reserves bandwidth based on the expected and latest arrival time, and departure time of the MT.

To keep the CDR below a predefined level, different bandwidth reservation schemes are suggested by using effective prediction mechanisms [2, 3, 4]. To obtain each MT's position in real-time, Chiu et al [2] proposed a scheme to predict the MT's moving direction using the Global Positioning System(GPS) technology. Choi et al [3, 4] use the aggregated moving history of an MT to predict the MT's moving direction. Further, they vary the number of reserved channels to keep the CDR below a target value.

Although it is clear that considering a cluster of cells instead of just the current cell or only a few neighboring cells is more effective for bandwidth reservation and admission control, none of the prior studies has looked at the following issues that are essential to provide a better understanding of the clustering concept. First, how many cells should be included in the cluster and how the cluster should be configured? Second, can we use different bandwidth reservation policies for different cells based on the moving pattern of the MTs? Next, what are the different tunable parameters that can be used to optimize one or more objective functions to satisfy the QoS requirements? Also, how do the cluster structure and performance change with a mixed workload of predictable users with well defined user profile and new/casual users without any user profile?

This paper attempts to answer these questions by proposing a clustering scheme that considers the possible path of the MT in defining a sector-type configuration. The size of the sector and the number of cells in the sector can be dynamically configured for each MT using it's mobility information. The sector of cells are further divided into two regions depending on whether they have an immediate effect on the handoff or not. The sector concept is similar to the MLC except that the MLC approach considers a homogeneous sector, whereas we consider a sector with two regions of cells and treat them differently. The number of cells in each region could be different. We propose a *differential bandwidth reservation(DBR)* algorithm that uses two separate reservation protocols for these two regions of cells. Cells next to the current cell (inner region) where the connection request is originated, have a direct impact on the handoff. Therefore, the cells in this region first attempt to reserve the requested bandwidth. If it does not succeed, they attempt to share the bandwidth. Cells far away from the current cell (in the outer region), on the other hand, use only bandwidth sharing since the MT may not move to this region. These two differential schemes make bandwidth reservation more adaptable and efficient compared to all prior policies, where a uniform bandwidth reservation approach was used for the cells in the cluster. Then, we enhance the performance of the DBR algorithm with a *user profile-based DBR (UPDBR)* policy that relies on the known mobility pattern of the MTs for better path prediction. The impact of different design parameters that affect the DBR and UPDBR algorithms are examined in detail.

We simulate a (6×6) wrap-around network of hexagonal cells to evaluate the effectiveness of the proposed schemes. We compare the DBR algorithm with two related schemes, TRUNK reservation [11] and PT_QoS [1]. Both voice and data traffics are used in simulating a multimedia-type wireless network. Simulation results indicate that the DBR algorithm is more adaptable to optimize the system performance compared to the prior schemes. In particular, it has the lowest CDR while maintaining competitive CBR and bandwidth utilization. The UPDBR scheme can exploit the path history for better bandwidth utilization as well as reduction in the number of communication messages compared to the DBR. The overall results show that the proposed schemes can not only provide better performance, but also exploit the current state of the system in optimizing different performance parameters.

The rest of this paper is organized as follows. Section 2 introduces the system model. The bandwidth reservation and admission control policies used in DBR are presented in Section 3. The UPDBR algorithm, based on the path history, is discussed in Section 4. Section 5 is devoted to performance evaluation and comparisons of the algorithms. Section 6 concludes the paper.

2 System Description

In cellular networks, a geographical area is divided into a number of hexagonal regions, called cells [5]. Each cell is supported by a base station (BS) located in the center of the cell. The BSs are connected to each other by a static wired network. Each mobile terminal (MT) in a cell communicates with the BS by wireless links. Each cell is assigned a fixed number of channels (or bandwidth). A channel can be a time slot, a frequency band, or a combination of both for time-division multiple access (TDMA), frequency-division multiple access (FDMA), or a hybrid scheme, respectively.

An MT may make a connection request from anywhere in any cell. Since an MT tends to keep its original moving direction, it has a lower probability of making a sudden turn compared to maintaining the current direction. Therefore, let us assume that an MT moves straight, left, right, lower left, lower right, and back with probabilities of P_S, P_L, P_R, P_{LL}, P_{LR}, and P_B, respectively. In this paper, we assume $P_S = 0.5$, $P_L = 0.15$, $P_R = 0.15$, $P_{LL} = 0.075$, $P_{LR} = 0.075$, and $P_B = 0.005$, similar to the moving pattern used in [4]. Further, we assume that the MT moves with a constant speed in a cell and changes (or may not change) direction at the cell boundary. The moving direction can be predicted by the Global Positioning System(GPS) or by the BS based on the signal strength measurements [12].

Since an MT has a much higher probability of maintaining its current direction, moving left, or moving right than the other three directions, there exists a sector of cells covered within an angle θ, to which the MT might move in the near future. This sector of cells can be classified based on their distance from the current cell. Let $r_{i,d}$ denote the cluster of cells located at a distance d away from the current cell c_i. Let $cell(\theta)$ denote the sector of cells located within an angle θ. Then, we have:

$$r_{i,d} = \{c_j | distance(c_i, c_j) = d \wedge c_j \in cell(\theta)\} \; d = 1, 2, \cdots, n$$

As shown in Figure 1, cluster $r_{i,1}$ consists of 3 cells, c_1, c_2, and c_3, while cluster $r_{i,4}$ has 7 cells, c_{12} to c_{18}. As the distance d increases, the number of cells in that cluster increases. Depending on the moving speed, mobility pattern, and the traffic flow of MTs, the sector angle θ and the maximum cluster distance n should be carefully chosen. For example, if the MT moves at a high speed, θ should be narrow and n is likely to be large. On the contrary, if the MT moves at a low speed, θ should be wide and n should be small.

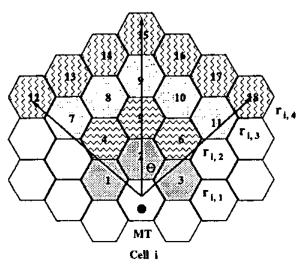

Figure 1. The cluster concept with a sector angle θ.

3 A Differential Bandwidth Reservation Algorithm

3.1 Bandwidth Reservation for Handoffs

To reduce the CDR, when making bandwidth reservations, it is more effective to consider a cluster of cells which includes cells located around or along the way to which the MT might move. Furthermore, there should be different bandwidth reservation policies for different cells depending on their distance from the current cell. For example, suppose an MT in cell c_i is likely to perform a handoff. BS_i first predicts the direction in which the MT might move based on the path of the MT, and then it constructs a sector of cells for bandwidth reservation. It is easy to see that the MT will most likely move to the cells closer to c_i, such as cells in $r_{i,1}$ and $r_{i,2}$ in Figure 1. Because the MT may change its direction at any time, it has relatively lower probability of moving to cells located far away from cell c_i, such as cells in $r_{i,4}$. Based on this observation, for each cell c_i, cells that are required for bandwidth reservations are classified into two different regions: $R_I(i)$ and $R_{II}(i)$.

- $R_I(i)$: It contains the cells located closer to c_i. For example, cells in $r_{i,1}$ and $r_{i,2}$ are close to c_i and they have a direct impact on CDR because the handoff will fail if the requested bandwidth is not available.
- $R_{II}(i)$: It contains the cells far away from c_i. For example, cells in $r_{i,3}$ and $r_{i,4}$ are 3, and 4 cell distant from c_i, and they only have indirect effects on handoff.

We call these regions as *inner* and *outer* regions, respectively. For each handoff request, a BS reserves bandwidth for cells in both regions. Since several BSs make their reservations for the corresponding handoff requests, a cell c_m may make several bandwidth reservations for different BSs. As an example, consider handoff requests from two cells c_i and c_j. BS_i and BS_j are supposed to make bandwidth reservations in several regions of cells; i.e., $R_I(i)$ or $R_{II}(i)$, and $R_I(j)$ or $R_{II}(j)$. As a result, c_m can be included in $R_I(i)$ or $R_{II}(i)$. Also, c_m can be included in $R_I(j)$ or $R_{II}(j)$. In this case, c_m reserves bandwidth for handoff requests from c_i and c_j. We apply different bandwidth reservation policies for a handoff request depending on the cell region.

When BS_m receives a handoff request from BS_i, it first identifies its reservation region. If c_m is in $R_I(i)$, BS_m makes bandwidth reservation using the condition:

$$N_{used}(m) + bw \leq N_{total} - N_{resv}(m) \qquad (1)$$

where $N_{used}(m)$ is the currently used bandwidth, *bw* is the requested bandwidth, N_{total} is total bandwidth of the cell, and $N_{resv}(m)$ is the currently reserved bandwidth. If the above condition is satisfied, BS_m replies to BS_i that it can satisfy the required bandwidth. If not, BS_m checks if it can *share* the already reserved bandwidth with other cells. When bandwidth sharing is used, the reserved bandwidth is not strictly assigned to any MT, and hence can be used by any MT in a first come first serve (FCFS) manner. To implement the idea, BS_m checks if the sum of $N_{resv,I}(m)$, *bw*, and the existing shared bandwidth ($N_{share,I}(m) + N_{share,II}(m)$) is less than or equal to ϵ times of $N_{resv}(m)$. Note that the shared bandwidth could be different in the inner and outer regions, and they are specified by two different terms. Here, ϵ is a system parameter which enables BS_m to reserve more than actually allocated bandwidth, i.e. $\epsilon \geq 1$ based on the QoS requirement of the system. If the condition is satisfied, BS_m sends a reply message to BS_i. Otherwise, the reservation request from BS_i is rejected.

If c_m is involved with $R_{II}(i)$, it may waste a large amount of bandwidth to reserve extra bandwidth since the MT has a relatively low probability to move into c_m. Thus, only bandwidth sharing is used for this region of cells. As a result, BS_m checks if the sum of $N_{resv}(m)$, *bw*, and the existing shared bandwidth is less than or equal to η times of $N_{resv}(m)$, and then decide whether it can share the bandwidth or not. Similar to ϵ, η is a system QoS parameter and

$\eta \geq 1$. Intuitively, η should be higher than ϵ to facilitate more sharing in the outer region.

```
if (c_m ∈ R_I(i)) {
    if (N_used(m) + bw ≤ N_total - N_resv(m)) {
        send agree to allocate bandwidth to c_i;
        N_resv(m) = N_resv(m) + bw;
    }
    else {
        if (N_resv(m) + bw + N_share,I(m) + N_share,II(m) * ε/η ≤ N_resv(m) × ε) {
            send agree to share bandwidth to c_i;
            N_share,I(m) = N_share,I(m) + bw;
        }
        else
            send reject to c_i;
    }
}
else { // c_m ∈ R_II(i)
    if (N_resv(m) + bw + N_share,II(m) + N_share,I(m) * η/ε ≤ N_resv(m) × η) {
        send agree to share bandwidth to c_i;
        N_share,II(m) = N_share,II(m) + bw;
    }
    else
        send reject to c_i;
}
```

Figure 2. The DBR Algorithm.

3.2 Admission Control for New Connections

Next we present the admission control policies for new connections. Whenever a new connection request is generated in a cell c_i, BS_i checks if Eq. 2. can be satisfied. If the condition is satisfied, BS_i constructs $R_I(i)$ and $R_{II}(i)$, and sends reservation request messages to the corresponding cells. Otherwise, the new connection is blocked.

$$N_{used}(i) + bw \leq N_{total} - N_{resv}(i) \quad (2)$$

When a cell, say c_j, in $R_I(i)$ or $R_{II}(i)$ receives a reservation request message from c_i, BS_j runs the algorithm shown in Figure 2, and replies to c_i whether it can accept the connection. After BS_i receives all reply messages from all cells in $R_I(i)$ and $R_{II}(i)$, it decides whether it can accept the new connection or not. It will be able to accept the connection only if it did not receive any *reject* message. In this case, it accepts the new connection and sends reservation confirm messages to the cells from which it receives a bandwidth allocation or bandwidth sharing message. Otherwise, the new connection is blocked. When BS_j receives a confirm message from c_i, BS_j reserves or shares the bandwidth.

BS_i uses a look-up table to save information about the cells which are involved in $R_I(i)$ and $R_{II}(i)$ based on the current MT's moving direction [16]. Once BS_i identifies the MT's moving direction using a technique as mentioned in Section 2, it checks the look-up table and finds out where the reservation requests should be sent without any further computation.

$$N_{used}(j) + bw \leq N_{total} \quad (3)$$

When a handoff occurs from cell c_i to cell c_j, BS_j checks the available bandwidth for handoff using Eq. 3. If the condition is satisfied, the handoff is successful. After the handoff is completed, BS_j reestablishes $R_I(j)$ and $R_{II}(j)$, and sends reservation request messages to the cells which are newly involved. If the cells which were in $R_I(i)$ or $R_{II}(i)$ are still involved in $R_I(j)$ or $R_{II}(j)$, they do not reserve or share the bandwidth again. BS_j sends release messages to the cells which are not involved in $R_I(j)$ and $R_{II}(j)$ so that they can release the reserved or shared bandwidth. In case of a handoff drop, BS_i sends release messages to the cells involved in $R_I(i)$ and $R_{II}(i)$ that were established before the handoff, and these cells will release the reserved or shared bandwidth.

4 An User Profile-Based DBR Algorithm

In this section, we extend the DBR algorithm for MTs whose moving path is known as *a priori*. We refer it to as *user profile-based DBR (UPDBR)* algorithm.

Several researchers have used user profile for better location and handoff managements [13, 14]. However, none of these studies consider the cell regions, and only used the current cell instead of a sector of cells. Intuitively, if the user profile of a set of MTs can be known, the DBR algorithm can be used more effectively, because the coverage angel θ becomes narrow, and hence the number of cells used in the DBR negotiation will be small.

In the UPDBR approach, most of the MTs choose their favorite paths, use them frequently whenever they move, and do not change the path unless otherwise required. Therefore, we can extract the mobility pattern from the user profile and use it to predict the moving paths of such MTs with high accuracy. For the UPDBR algorithm, we assume the following:

- There are two groups of MTs. One is user profile-based group, denoted as G_f, and the other is non-user profile-based group, denoted as G_{nf}. The MTs in the G_f group have repetitive travel behavior, whereas MTs in the G_{nf} group exhibit little predictable behavior.
- The cellular network has the most recent statistical data for each MT in the G_f group. An MT in the G_f group has a probability of ρ to follow the predicted path.

Whenever a new connection is generated in a cell c_i, BS_i checks whether the MT belongs to the G_f or G_{nf} group by searching its ID and user profile in the database. For bandwidth reservation, if the MT belongs to G_f, BS_i establishes $R_I(i)$ and $R_{II}(i)$ in the same manner as the DBR algorithm except that fewer cells are involved. If the MT belongs to G_{nf}, BS_i applies the bandwidth reservation policy described in Section 3.

When a new connection request is generated in c_i, BS_i first determines the cells involved in P_{UPDBR} [1], and then it checks available bandwidth using Eq. 2. If the condition is satisfied, BS_i establishes $R_I(i)$ and $R_{II}(i)$, and sends reservation request messages to the cells in P_{UPDBR}. The procedure after that is the same as the DBR scheme. When a handoff occurs from a cell c_i to a cell c_j, BS_j checks the available bandwidth for handoff using Eq. 3. In certain situations, an MT may not use the predicted path due to conditions such as traffic congestion or other abnormal events. In such cases, whenever BS_i detects that the MT deviates from the usual path, it transfers the MT from G_f to G_{nf} group.

5 Performance Evaluation

We use a (6 × 6) wrap-around cellular network with 1 mile cell diameter to examine the proposed schemes. We consider two different types of communication sessions: voice and video. The connection time (T) is exponentially distributed with a mean of 180 seconds, and the connection arrival follows the Poisson distribution with a rate of λ. The speed of the MTs is uniformly distributed between 45 to 70 miles per hour. The total bandwidth allocated to each cell is 600 kb/s. The voice and the video connections require 10 kb/s and 100 kb/s, respectively. The percentage distribution of voice and video connections is given by $P_{voice} = 0.8$ and $P_{video} = 1 - P_{voice} = 0.2$.

We have written an event-driven simulator using CSIM to conduct the performance study. The simulation results are illustrated as a function of the offered load, where offered load is defined as

$$OfferedLoad = T \times \lambda \times (P_{voice} \times B_{voice} + (1 - P_{voice}) \times B_{video}) \quad (4)$$

For a given offered load, we can find the arrival rate λ from Eq. 4. In order to simulate the UPDBR scheme, we assume that 70% of the traffic in a cell follows the path defined in the user profiles, while the rest (30%) is assumed to be communication sessions with unknown user profiles. Moreover, it is assumed that an MT follows P_{UPDBR} 80% of the time ($\rho = 0.8$). The ϵ & η values are chosen between 1-3.

We measure the performance parameters such as connection blocking rate (CBR), connection dropping rate (CDR), bandwidth utilization, and the number of communication messages. The results are collected using 90% confidence interval and the predicted values lie within ± 10% of the mean. Here we include a subset of the result due to space limitation. For additional results, please refer to [9].

We analyze and compare the performance of our DBR approach with two previously proposed bandwidth reservation policies: the TRUNK approach and the PT_QoS approach. In the *trunk reservation (TRUNK)* approach, a fixed amount of bandwidth, g, out of the total bandwidth in a cell is exclusively reserved for handoffs. This scheme relies only on local information to admit a new connection. The *Predictive Timed QoS guarantees (PT_QoS)* approach defines an MLC (Mostly Likely Cluster) based on the mobility pattern of the MTs, and reserves bandwidth based on parameters such as the MT's expected arrival time, the latest arrival times, and the departure time [1]. Unlike our scheme, where a new connection is admitted if a certain percentage of cells can support the connection, the PT_QoS approach drops the connection if the MT does not arrive in the cell by the latest arrival time.

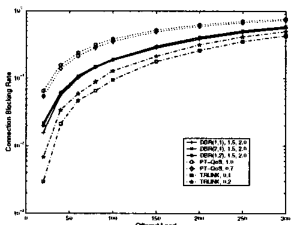

Figure 3. Comparisons of the CBR of the DBR approach (ϵ =1.5 and η = 2.0) to the TRUNK approach (g = 0.1, 0.2), and the PT_QoS approach (s = 1.0, 0.7)

Figure 3 shows the CBRs of the three policies. We consider three sector configurations using up to three clusters; i.e., $n = 3$. In the first configuration, we use DBR(1,1) to represent the configuration of one cluster in R_I and one cluster in R_{II}. In the second case, we use DBR(2,1) to represent the configuration of two inner clusters in R_I and one outer cluster in R_{II}. Finally, we use DBR(1,2) to represent one inner cluster in R_I and two outer clusters in R_{II}. As shown in Figure 3, when the offered load increases, the TRUNK approach has lower CBR than DBR and PT_QoS because it only examine the status of the current cell where the new connection request is initiated. Hence, the new connection request has a better chance to be accepted. The PT_QoS scheme has the maximum CBR because it reserves a large amount of bandwidth for a longer time. The DBR approach has a lower CBR than the PT_QoS approach, but slightly higher CBR than the TRUNK approach for the three combinations of sector configurations.

Figure 4 shows the connection dropping rates (CDRs) of three approaches. As can be seen, the DBR policy has the lowest CDR compared to the other two schemes regardless of the sector configuration. As we mentioned earlier, dropping a connection is more annoying, and hence most algorithms have to limit the CDR to a certain level. For example, an acceptable CDR of 0.01 has been used as a target QoS in prior studies [3, 4]. The PT_QoS approach has a lower CDR than the TRUNK approach except for g = 0.2, which shows a little lower CDR than the PT_QoS approach with s = 0.7 when the offered load is high. For the PT_QoS approach, s = 0.7 has a higher CDR than s = 1.0, because

[1] P_{UPDBR} denotes the set of cells involved in the predicted path when using the UPDBR algorithm.

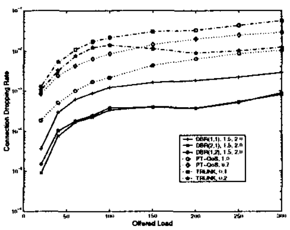

Figure 4. Comparison of the CDR of the DBR approach (ϵ = 1.5 and η = 2.0) to the TRUNK approach (g = 0.1, 0.2), and the PT_QoS approach (s = 1.0, 0.7)

the former (s=0.7) accepts more connections. Among the three sector configurations, DBR(2,1) and DBR(1,2) have lower CDR than DBR(1,1) because more cells are examined in these two configurations (DBR(2,1) and DBR(1,2)) when admitting a new connection.

6 Concluding Remarks

In this paper, we proposed a Differential Bandwidth Reservation(DBR) algorithm for effectively handling call handoffs and admission of new calls in multimedia wireless networks. With this scheme, the possible path of an MT that spans over a set of cells is divided into a couple of clusters in the form of a sector. The cells in the sector are further divided into two regions depending on whether they have an immediate impact on the handoff or not. In the region closer to the handoff initiating cell, we first check for exclusive bandwidth reservation. If the requested bandwidth is not available, then the possibility of sharing the already reserved bandwidth is examined. In the outer region, where the MT has a lower probability to move, only bandwidth sharing is used to accommodate more calls. A handoff request is accepted when all the cells of both the regions agree to accept the call. A variation of the DBR algorithm, called UPDBR, exploits the moving pattern of an user to make more efficient bandwidth reservation by minimizing the number of participating cells in handoff.

Extensive simulations were conducted to compare the performance of the proposed schemes with similar techniques such as the TRUNK policy and PT_QoS policy. It was shown that the DBR scheme can provide lower connection dropping rate compared to the TRUNK and PT_QoS policies, while maintaining competitive call blocking rate and bandwidth utilization. In addition, due to applying two different bandwidth reservation mechanisms in the two regions, it is possible to optimize specific performance parameters as required. The UPDBR algorithm, as expected, is capable of providing better bandwidth utilization, and keeps the number of communication messages small.

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