Adaptive Bandwidth Reservation Mechanism Using Mobility Probability in Mobile Multimedia Computing Environment

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Abstract

In this paper, ARMM(Adaptive-bandwidth Reservation Mechanism using MPP) is proposed to provide the consistent QoS guarantees for multimedia traffics in a mobile computing environment. Each cell can reserve fractional bandwidths for hand-off calls to its adjacent cells, and this aggregated reservation of bandwidth can only be used for hand-off calls and not for new calls. It is important to determine the right amount of reserved bandwidth for hand-off calls. Because the blocking probability of new calls would increase if we reserve more bandwidth than being necessary. This paper proposes an algorithm based on a MPP(Mobility Pattern Profile) and a 2-tier cell structure to determine the amount of bandwidth to be reserved in the cell and to dynamically control its amount based on its network condition.

1. Introduction

Recent advances in high-speed wireless networking have made it possible for a user to be able to process data regardless of his/her physical location, even on the move[1]. There has also been a great demand for processing multimedia data such as video, audio library, image and so on.

The most important issue in providing multimedia traffic on a mobile computing environment is to guarantee the mobile host(client) with consistent QoS(quality of service). Due to its communication-intensive nature, multimedia applications may impose severely a burden on the wireless networking component of mobile computing environments. The fundamental problem is that the wireless network is a scarce shared resource to guarantee a consistent QoS. As a result, it is difficult to provide consistent QoS guarantees on a mobile computing environment. The provision of QoS in wireless networks becomes even more complicated due to client mobility. The QoS negotiated between the client(application) and the network in one cell may not be honored due to client mobility, causing hand-offs between cells[2-7][9][11].

One of the most important issues in guaranteeing high degree of QoS is how to reduce hand-off drops caused by lack of available bandwidth in the new cell. Each cell can reserve fractional bandwidths of hand-off calls to its adjacent cells, and this aggregate reserved bandwidth, of multiple hand-off calls, can only be used for hand-offs and not for new calls. It is also important to determine how much of the bandwidth should be reserved for hand-off calls because reserving too much bandwidth for these calls would increase the probability of a new call being blocked and vice versa. Therefore, it is essential to develop a new mechanism to provide QoS guarantee in a mobile computing environment, by reserving an optimal amount of bandwidth.

In this paper, ARMM(*A*daptive-bandwidth *R*eservation *M*echanism using *M*PP) is proposed to guarantee a consistent QoS for multimedia traffics in mobile computing environments. We propose a next location-prediction algorithm based on an MPP(Mobility Pattern Profile) and a 2-tier cell structure for reserving a near-optimal amount of bandwidth for hand-off calls. We also propose an algorithm that adaptively readjusts the amount of reserved bandwidth based on network conditions. A common pool approach to reserved bandwidth at each cell and an adaptive QoS scheme has been used to account for the waste of bandwidth caused by an erroneous prediction.

The paper is organized as follows. After discussing briefly previous work on the bandwidth reservation mechanism in mobile computing environment in Section 2, we describe our ARMM mechanism in detail in Section 3. Section 4 describes the simulation results and compares the performance of our mechanism with other that of other mechanisms under various scenarios. Finally, Section 5 contains the concluding remarks and future works.

2. Related Work

The characteristics of multimedia, wireless network and movement need to be examined first, in order to apply multimedia services on mobile computing environments. Two types of traffic are assumed in wireless networks, class I and class II : i. Class I - real-time traffic data types such as audio and video that are delay sensitive ii. Class II - non real-time traffic data types such as images and text. The bandwidth of the wireless network environment is scarce compared to that of the wired network environment and mobility further complicates the client's network environment.

A call can be classified into a new call and a hand-off call representing a new call made by the cell and a call that moves from one cell to another respectively. A hand-off call is considered to be of higher priority due to its active status.

Following are some of the results of the resource reservation mechanisms that have been done on providing the client with consistent QoS.

Due to its delay-sensitive nature, the QoS of a class I call can be downgraded or even dropped when there is an insufficient bandwidth available. To prevent a class I call from being dropped due to such problem, resource reservation mechanism is used to reserve the required resource on its neighboring cell. The mechanism is used to provide a call with the resource required to provide seamless class I service during hand-off.

However, while bandwidth reservation would guarantee seamless mobility on a hand-off call, it could increase the probability of a new call being blocked because the reserved bandwidth cannot be used for new calls. On the other hand, reducing the reserved bandwidth would increase the probability of hand-off drops. To prevent such problems, a method is needed to determine the right amount of bandwidth to be reserved for hand-off calls. Oliveira[7] proposed the mechanism that would take the network condition of each cell into account in reserving the amount of bandwidth using the hand-off dropping probability and bandwidth utilization. If the probability of hand-off drops is above(below) the threshold, the amount of reserved bandwidth is increased(decreased) by a pre-specified factor. If the probability of hand-off calls being dropped becomes 0 and the bandwidth utilization is lower(upper) than the threshold, the amount of reserved bandwidth is decreased(increased) by a pre-specified factor.

If BS can predict the next move of the client, it would only have to reserve bandwidth for that particular cell[6][9]. Lu[9] and Choi[6] proposed a mechanism of predicting the next move of the client based on probability by analyzing the data on their previous movement pattern. Lu[9] mechanism is based on the call's previous movement pattern and Choi[6] mechanism is based on an aggregate history of hand-offs observed in each cell.

Lu[9] mechanism makes its bandwidth reservation based on the client's previous path of movement. This mechanism only reserves resource on the cell the call is most likely to be hand-off to instead of reserving bandwidth on all of its neighboring cells. However, if the hand-off does not occur to the reserved cell, it results in a waste of bandwidth resource. Choi[6] mechanism predicts mobile's directions and hand-off times in a cell and reserves the bandwidth calculated by estimating the sum of fractional bandwidth of expected hand-off calls within time unit. This mechanism only considers one-dimensional cellular structure. Therefore, the mechanism is considered to be unrealistic.

3. Bandwidth Reservation Mechanism Based on a MPP and a 2-Tier Cell Structure

3.1 Next-Cell Prediction and Mobility Probability based on MPP

Figure 1 shows the framework of ARMM. When the client makes a Class I or Class II call, BS makes bandwidth reservation on its neighboring cells to support consistent QoS of Class I calls. The amount of reserved bandwidth should be estimated before reserving bandwidth in its neighboring cells.

The amount of reserved bandwidth is estimated using the next-cell prediction algorithm, 2-tier cell structure and the mobility probability. Bandwidth reservation in its neighboring cells is based on the partition of cell bandwidth and bandwidth reassignment scheme.

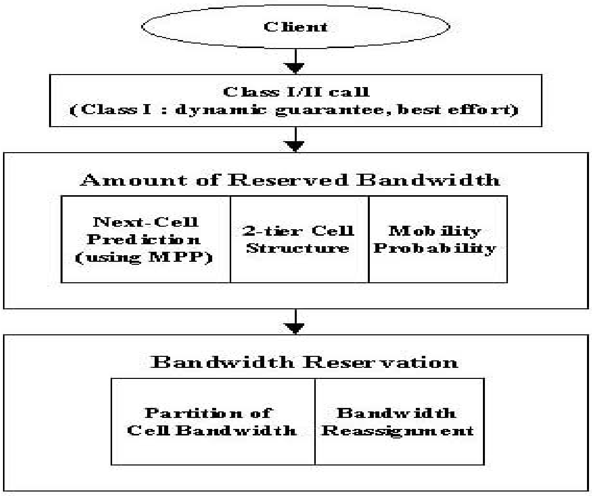

Figure 1. The Framework of ARMM

In this paper, an MPP(mobility pattern profile) has been designed to estimate user mobility based on an aggregate history of hand-offs observed in each client. Table 1 shows MPP structure. The role of each field can be defined as below :

Table 1. MPP Structure

PrevBSID	CurrBSID	NextBSID	NextCount

CurrBSID represents the index of a cell in which the client is currently residing and PrevBSID is the index of the previous cell in which the client resided before entering the current cell. NextBSID is the index of the cell that the client entered after departing from the current cell CurrBSID. More than one NextBSID may exist. NextCount is the number of times the client has moved from the current cell(CurrBSID) to a NextBSID. NextCount is incremented every time the client moves from the current cell to a NextBSID. The mobility probability is obtained using the MPP, as shown in (1):

$$MP_{ij}^{x} = \frac{NextCount\ of\ r_{x,j}}{\sum_{k=1}^{n} NextCount\ of\ r_{x,k}} \qquad (1)$$

where i and j are the client's CurrBSID and NextBS, respectively, and the NextBSID of client x is assumed to be $\{r_{x,1}, r_{x,2}, \ldots, r_{x,n}\}$. (1) calculates the probability of client x moving from cell i to j and ARMM utilizes the probability to predict the next move of the client.

The client's next movement, NextBS, can easily be predicted to be X, Y and Z using Table 2, when the PrevBS and the NextBS of the client is assumed to be A and B respectively. The probability of the client moving to X is approximately 0.88(157/178), to Y 0.11 and to Z 0.01 each according to the Table 2. Therefore, it can be concluded that the client is most likely to move from cell B to cell X.

Table 2. A Snapshot of the MPP

PrevBSID	CurrBSID	NextBSID	NextCount
⋮	⋮	⋮	⋮
A	B	X	157
		Y	20
		Z	1
O	P	I	50
		J	50
⋮	⋮	⋮	⋮

A threshold of the mobility probability(TMP) has been set in this paper. More bandwidth is reserved for clients with a mobility probability above the TMP than for those below the TMP in the ARMM. The scheme is used to probabilistically predict the client's direction using its MPP, and dynamically adjusts the amount of reserved bandwidth according to the estimated mobility probability.

In this paper, bandwidth reservation is carried out separately for clients with a mobility probability above and below the TMP. The TMP is set to be 0.75.

- NextBSID with a mobility probability above the TMP : BS reserves bandwidth on a single NextBSID. As shown in Table 2, BS only reserves bandwidth in cell *X*(MP = 0.88) if the client currently resides in cell *B* through cell A.
- NextBSID with a mobility probability below the TMP : BS reserves bandwidth on more than two NextBSID's. As shown in Table 2, BS reserves bandwidth in cell *I*(MP=0.5) and cell *J*(MP=0.5) respectively, if the client currently resides in cell *P* through cell *O*.

The mechanism of determining the amount of reserved bandwidth is further described in section 3.3. To prevent the increase of the MPP, a NextBSID with a low mobility probability is deleted through the MPP optimization process.

3.2 The 2-Tier Cell Structure

Bandwidth is reserved only for class I calls due to the nature of their delay-sensitive. However, if a client with a class I call resides in a particular cell for a long period of time before being hand-off, network bandwidth may be wasted due to bandwidth reservation. To prevent such problem, this paper proposes the 2-tier cell structure, as shown in Figure 2.

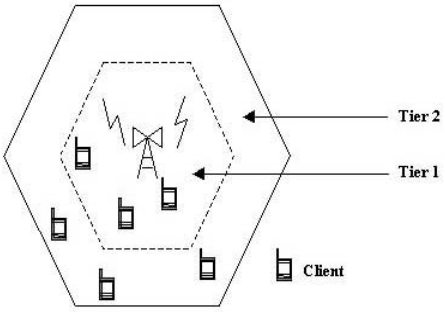

Figure 2. 2-Tier Cell Structure

BS propagates a beacon message to its cell area to keep track of the location of its clients.

The PSS(pilot signal strength) is degraded with increasing propagation distance between the BS and the client. It implies that the hand-off probability of the client increases with the increase of propagation distance from the BS. The 2-tier cell structure utilizes such characteristic to predict the moment of triggering the hand-off. The location of the client in the cell is designated by its PSS. Clients with a PSS below the average signal strength are located in "Tier-2" while those with a PSS above the average signal strength in "Tier-1". BS reserves bandwidth in its neighboring cells to support the hand-off of clients that only reside in "Tier-2". It is because the clients in "Tier-2" have a higher probability of moving to another cell than those in "Tier-1".

3.3 ARMM

The traffic taken up by the clients are classified into class I(real-time traffic) and class II(non real-time traffic) in this paper. In the hand-off, bandwidth is reserved for clients in "Tier-2" with a class I call. A common pool of resources at each cell and an adaptive QoS scheme has been used to account for the waste of bandwidth caused by an erroneous prediction. The common pool approach allows class I connections to share the reserved bandwidth. The client negotiates with the BS upon the minimum and maximum amount of bandwidth with which it would be provided in the hand-off. The adaptive QoS scheme dynamically adjusts the QoS within the pre-specified bound depending on dynamic network conditions. In order to set up a connection, the client may require b^{max} and b^{min} of bandwidth for the maximum QoS and the minimum QoS, respectively.

The call admission control mechanism introduced in this paper drops a class I hand-off call if its minimum bandwidth request does not reach b^{min}, whereas any class II hand-off calls with a minimum bandwidth request greater than 0 is accepted.

The bandwidth of a cell is divided into three parts as shown in Figure 3.

C_e	C_d	C_h

Figure 3. Partition of Cell A's bandwidth

Each cell has a link capacity C_{tot} and at time *t*, $C^t_{A,tot}$ can be calculated by (2) :

$$C^t_{A,\,tot} = C^t_{A,\,e} + C^t_{A,\,d} + C^t_{A,\,h} \quad (2)$$

where $C^t_{A,e}$ is the sum of all the bandwidth that are consumed by the clients residing in cell A, $C^t_{A,h}$ is the sum of all the bandwidth that have been reserved in advance, and $C^t_{A,d}$ is the amount of remaining bandwidth.

The bandwidth reserved for $C_{A,d}$ will be consumed in the following cases :

- Case I : shortage of bandwidth reserved for hand-off calls(C_h)
- Case II : new call from cell A
- Case III : QoS upgrade by a client within cell A

Case I has the highest priority and followed by Case II and III.

Assuming that *n* is the number of clients residing in cell A, the bandwidth of $C^t_{A,e}$ can be calculated :

$$C^t_{A,e} = \sum_{e=1}^{n} b_e^{current} \quad (3)$$

where $b_e^{current}$ is the amount of bandwidth consumed by the clients in cell A, and $b_e^{\max}\,(b_e^{\min})$ is the maximum(minimum) amount of bandwidth requested by the client. The bound of the amount of bandwidth is $(\sum_{e=1}^{n} b_e^{\min} \le C^t_{A,e} \le \sum_{e=1}^{n} b_e^{\max})$.

The BS of each cell makes bandwidth reservation of neighboring cells for its clients residing in the "Tier-2" of its cell. The mobility probability of a client can be above or lower than the TMP. The mechanism used in this paper takes a different approach to bandwidth reservation for two cases mentioned above. The total amount of reserved bandwidth, $R_{A,\,N_1}$, is given by (4) :

$$R_{A,N_1} = w_1 \times \sum_{hc_{up}=1} b_{hc_{up}}^{current} + w_2 \,(\sum_{hc_{down}=1} b_{hc_{down}}^{current} \times MP_{A,\,N}^{hc_{down}}$$

$$+ \sum_{hc_{random}=1} b_{hc_{random}}^{current} \times 1/6) \;\; (0 < w_1 < 1,\, 0 < w_2 < 1) \quad (4)$$

where N_1 is a neighboring cell of cell A, $b_{hc}^{current}$ is the amount of bandwidth consumed by a client to be hand-off, and MP^{hc}_{A,N_1} is the hand-off probability of client c to cell N_1 from the current cell A.

R_{A,N_1} is the amount of bandwidth reserved for the hand-off to occur from cell A to cell N_1. The BS of cell A notifies cell N_1 of the amount of bandwidth to be reserved, indicated by R in (4). Weight w_1 and w_2 are design parameters between 0 and 1. The bandwidth reserved for a client(hc_{up}) with a mobility probability higher than the TMP, is calculated by multiplying the sum of $b^{current}_{hc_{up}}$ to w_1. If the mobility probability is lower than the TMP, the reserved bandwidth of a client(hc_{down})is calculated by multiplying the sum of $b^{current}_{hc_{down}} \times MP^{hc_{down}}_{A,N_1}$ it by weight w_2. The amount of bandwidth reserved for a client(hc_{random}) that has never visited the cell before, $b^{current}_{hc_{random}}$ is calculated by multiplying 1/6[1] to it and then again by w_2.

The reason for multiplying an aggravation weight of w_1 or w_2 to each bandwidth is that it is very unlikely that all class I calls in cell a will move to another cell at the same time.

The mobility probability is multiplied by hc_{down} and hc_{random} to adjust the amount of reserved bandwidth according to the hand-off probability from cell A to cell N_1. The mobility probability of a client above the TMP is assumed to be 1. Therefore, the bandwidth reservation scheme reserves more bandwidth for hc_{up} than hc_{down} and hc_{random}. The amount of bandwidth reserved for cell A in each of its adjacent cells is estimated by (4).

The sum of the bandwidth reserved in cell A for its neighboring cells, $C^t_{A,h}$ can be calculated with (5) :

$$C^t_{A,h} = \sum_{i=1}^{6} R_{N_i,A} \quad (5)$$

where N_1, N_2, N_3, N_4, N_5, and N_6 represent a neighboring cells.

The BS of cell A compares the amount of bandwidth available($C_{available} = C_{tot} - C_e$) with $C_{A,h}$ prior to reservation.

If $C_{A,h}$ exceeds $C_{available}$, we "borrowed"(reassigned) some bandwidth from already existing class II connections to allocate the reserved bandwidth of the class I hand-off calls. The QoS of class II clients are not affected much by the reassignment due to its insensitivity to delay. If $C_{A,h}$ still exceeds $C_{available}$ after the reassignment, we should borrow bandwidth reserved for class I hand-off calls. The client with a class I hand-off call chooses between the "best-effort" call and the "dynamic guarantee" call upon setting up connection with the BS. The characteristic of each call is illustrated below.

- "best-effort" : This type of call is provided with a QoS within the bound of b^{min} and b^{max} if $C_{A,h}$ exceeds b^{min}. If $C_{available}$ is insufficient, we borrow bandwidth of class I calls. The QoS is adaptively re-adjusted for the "best effort" call in the hand-off, if necessary. The QoS being provided by the cell may vary within the bounded range due to the reassignment.
- "dynamic guarantee" : As is the case with the "best-effort" call, "dynamic guarantee" call is provided with a QoS within the pre-specified bound if $C_{A,h}$ exceeds b^{min}. However, this scheme does not reassign bandwidth of "dynamic guarantee" calls even if $C_{available}$ is insufficient. The QoS is adaptively re-adjusted for the "dynamic guarantee" call in the hand-off, if necessary. The client is provided with the readjusted QoS guarantee level and receives a higher priority level than a "best-effort" call in case of QoS upgrade.

A client being provided with either a "best-effort" or a "dynamic guarantee" call is guaranteed to receive the minimum bandwidth, b^{min} required for a seamless QoS. When a hand-off occurs, the cell readjusts the QoS within the pre-specified bounds. A "best-effort" call is not guaranteed to receive the same QoS because of the reassignment of bandwidth. On the other hand, a "dynamic guarantee" call is guaranteed to receive the readjusted QoS level..

The actual amount of bandwidth reserved in the cell(C_{h_re}) and C_d can be calculated using a bandwidth reservation algorithm shown in Figure 4, where Cborrow1 and Cborrow2 is the bandwidth reassigned by Class II and "best-effort" Class I calls respectively.

```
bandwidth_reservation algorithm( ) {
Input : $C_{available}$, $C_h$
Output : $C_{h\_re}$, $C_d$
if($C_{available} \geq C_h$) {
    $C_{h\_re} = C_h$;
    $C_d = C_{available} - C_h$; }
else if ($C_{available} + C_{borrow1} \geq C_h$) {
    $C_{h\_re} = C_h$;
    $C_d = C_{available} + C_{borrow1} - C_h$; }
else if ($C_{available} + C_{borrow1} + C_{borrow2} \geq C_h$) {
    $C_{h\_re} = C_h$;
    $C_d = C_{available} + C_{borrow1} + C_{borrow2} - C_h$; }
else {
    $C_{h\_re} = C_{available} + C_{borrow1} + C_{borrow2}$;
```

---

[1] The shape of the mobile computing environment is assumed to be a hexagon in this paper. Therefore, the number of adjacent cells is 6 and the mobility probability is 1/6

```
        $C_d = 0$;}
}
```

Figure 4. Bandwidth Reservation Algorithm

If $C_{available}$ is larger than C_h, bandwidth is reserved in the amount of C_h. However, if $C_{available}$ does not meet the requirements of C_h, either bandwidth reserved for Class II calls or both Class I and Class II calls need to be reassigned to meet the requirements. If C_h is still larger than $C_{available}$ after the reassignment of bandwidth, the sum of the bandwidth of $C_{available}$, $C_{borrow1}$, and $C_{borrow2}$ are reserved.

It is assumed that the simple call admission control used in this paper accepts the call if BS can provide either the hand-off call or the new call with a bandwidth of more than b^{min}. Class II calls are accepted as long as there is some unused bandwidth. BS processes a hand-off call using the following algorithm(Figure 5), in case of a client hand-off.

```
hand-off_call algorithm( ) {
/* $b^{current}$ is amount of bandwidth assigned to a hand-off call*/
Input : $b^{current}$ of hand-off call
Output : accept or drop call
if Class I {
    if($b^{current} \le C_h + C_d$) {
        accept call;
        allocate $b^{current}$;}
    else if ($b^{min} \le C_h + C_d < b^{current}$) {
        accept call;
        allocate $b^{readjusted}$;}
      /*$b^{min} \le b^{readjusted} < C_h + C_d$ */
    else /* $C_h + C_d < b^{min}$ */
        drop call;
}
else { /* Class II */
    if($C_h + C_d > 0$) {
        accept call;
        allocate $b^{readjusted}$; }
      /* $b^{min} \le b^{readjusted} \le C_h + C_d$ */
    else /* $C_h + C_d < 0$ */
        drop call;
}
}
```

Figure 5. A pseudo code of the algorithm to allocate bandwidth for hand-off call in each Cell

BS supports the hand-off calls through C_h and C_d. For Class I hand-off calls, if the sum of C_h and C_d is larger than $b^{current}$, BS supports the current QoS, but readjusts the amount of bandwidth if the sum is smaller than $b^{current}$. However, if the sum is smaller than b^{min}, the call is dropped. For Class II hand-off calls, the call is accepted if there is any available bandwidth, but drops the call otherwise.

In case of a new call, BS supports the call using the algorithm shown in Figure 6.

```
new_call algorithm( ) {
    Input : $b^{max}$ and $b^{min}$ of a new call
    Output : accept or block call
    if Class I {
        if($b^{max} \le C_d$) {
            accept call;
            allocate $b^{max}$;}
        else if ($b^{min} \le C_d < b^{max}$) {
            accept call;
            allocate $b^{readjusted}$;}
            /* $b^{min} \le b^{readjusted} \le C_d$ */
        else /* $C_d < b^{min}$ */
            block call;
    }
    else { /* Class II */
        if($C_d > 0$) {
            accept call;
            allocate $b^{readjusted}$; }
            /* $b^{min} \le b^{readjusted} \le C_d$ */
        else
            block call;
    }
}
```

Figure 6. A pseudo code of the algorithm to allocate bandwidth for new call in each Cell

BS supports the new call using C_d. In case of a client with a Class I call, the requested QoS is provided if the bandwidth of the call(b^{max}) is smaller than C_d, but readjusts the amount of bandwidth($b^{readjusted}$) if larger. The call is blocked if the bandwidth allocated by the call is smaller than b^{min}. In case of a client with a Class II call, the call is accepted if there is any available bandwidth, but blocks the call otherwise.

4. Performance Evaluation

In this section, we compare the performance of the ARMM with that of other existing mechanisms such as the No Reservation, Fixed Reservation, and Adaptive Reservation.

4.1 Other Mechanisms Simulated for Comparisons

The No Reservation(NR) mechanism does not reserve bandwidth in neighboring cells for hand-off calls. A new call, regardless of whether it is a Class I call or a Class II call, is accepted when its required amount of bandwidth is available in the cell where the new call is generated. Otherwise it is blocked. A Class I hand-off call is accepted when the minimum required bandwidth(b^{min}) is available in the cell that the hand-off call is to be migrated. A Class II hand-off call is accepted as long as there is some bandwidth available in the cell that the hand-off call is to be migrated. This mechanism is effective in that it supports high bandwidth utilization and low blocking probability of new calls. The drawback of this mechanism is its high dropping probability of hand-off calls.

The Fixed Reservation(FR) mechanism permanently reserves a portion of its bandwidth for hand-off calls. This reserved bandwidth may not be utilized by new calls. A new call is accepted if the minimum required bandwidth(b^{min}) is available in the remaining portion of the cell that the call is generated. Otherwise it is blocked. A Class I hand-off call is accepted when the minimum required bandwidth(b^{min}) is available in the reserved portion of the cell that the hand-off call is to be migrated. A Class II hand-off call is accepted as long as there is some bandwidth available in the cell that the hand-off call is to be migrated. Otherwise it is blocked. In this mechanism, the dropping probability of hand-off calls is low whereas the blocking probability of new calls is increased. The other drawback this mechanism is its low bandwidth utilization because it does not adjust the amount of reserved bandwidth based on the network conditions.

The Adaptive Reservation(AR) mechanism adaptively adjusts the amount of reserved bandwidth based on the network conditions. In this mechanism, each BS constantly monitors the hand-off dropping probability and the reserved bandwidth utilization. The hand-off dropping probability is the primary measure used to adjust the size of the reserved bandwidth. The reserved bandwidth utilization is used only when there is no dropping of hand-off calls. When the monitored hand-off probability is larger(smaller) than a fraction $threshold_{up1}(threshold_{down1})$ of the desired hand-off probability, AR increases(decreases) the amount of reserved bandwidth by a pre-specified factor $up_1(down_1)$. If the monitored dropping probability becomes 0 and the utilization of reserved bandwidth is above(below) a threshold value $threshold_{up2}(threshold_{down2})$, the amount of reserved bandwidth is increased(decreased) by a pre-specified factor $up_2(down_2)$. The process for handling new calls and hand-off calls is the same as that of the Fixed Reservation mechanism. Because this mechanism adaptively adjusts the amount of reserved bandwidth by a pre-specified factor based on the network conditions, it may not be able to cope with a rapid change in the number of clients.

4.2 Simulation Environment

The mobile computing environment used in this simulation is composed of 100 cells, with a diameter of 1Km, each cell keeping contact with its six neighboring cells with a bandwidth of 30Mb. The mobile speed range of the client is 5~80Km/h. New call requests are generated according to a Poisson process with rate λ(calls/second/cell) in each cell. A newly-generated call can appear anywhere in the cell with an equal probability.

The Table 3 shows the six typical traffic classes used in the simulation. It is assumed that new calls from all six traffic classes are generated with equal probability[7].

Table 3. Multimedia Traffic Used in Simulations

Traffic Class	Bandwidth Requirement	Average Call Duration	Example
Class I	30Kbps	3 minutes	Voice Service
Class I	256Kbps	5 minutes	Video-Phone
Class I	1~6Mbps	10 minutes	Video on Demand
Class II	5~20Kbps	0.5 minutes	E-mail, Paging
Class II	64~512Kbps	3 minutes	Remote Login & Data on Demand
Class II	1~10Mbps	2 minutes	FTP

We have used the [10], which is based on the actual movement behavior commonly observed in humans, to make the modeling more accurate and close to real-world. The movement patterns of humans observed in [10] are shown in Table 4.

Table 4. Movement Statistics

Trip Purpose	Percentage of Trip	Average Trip Length(miles)
To/From Work	0.202	10.65
Work-Related Business	0.014	28.2
Personal Business	0.529	6.74
Social/Recreation	0.253	11.53
Vacation	0.002	218.22

"To/From Work" is the figure of the user movement of commuters, and "Work-Related Business" represents the user movement from his/her work to other areas. "To/From Work" has a high mobility probability since it is a regular movement pattern. "Personal Business" is used to specify non-commuter movements, moving relatively short distances such as going to the hospital or shopping. Since "Personal Business" is a movement with a certain destination, the direction is rarely "Random" and its mobility probability usually shows a high figure although not quite as high as that of "To/From Work". "Social/Recreation" statistics indicates the commuter movements during non-business hours. The percentage of trips for "Social/Recreation" usually shows a low figure since it is a movement pattern for recreational/social purposes. We can see that "Vacation" is a movement pattern with a "Random" direction but a low percentage of trips figure. The user movement pattern, a figure for the percentage of trips and the distance traveled shown in the Table 4 have been used to make the simulation as close to the real-world situation as possible.

Suppose that FR reserves 20% of its bandwidth for hand-off calls and AR sets an upper(lower) threshold of hand-off dropping probability to 1.0(0.75) and an upper(lower) threshold of reserved bandwidth utilization to 0.75(0.25). The bandwidth reservation mechanism introduced in this paper sets the TMP to a relatively high figure(0.75) to minimize erroneous predictions.

4.3 Simulation Results and Their Analysis

In this section, we evaluate the four mechanisms under investigation in terms of the arrival rate of new calls. For the fairness of the simulation, we assume that AR also performs the bandwidth reassignment scheme.

Table 5 shows the performance parameters and metrics adopted for analyzing the performance of each mechanism.

Table 5. Performance Parameters and Metrics

Performance Parameters	Performance Metrics
Arrival rate of new calls	CBP
	CDP
	Bandwidth Utilization

The arrival rate of new calls is a rate of new calls measured as the average number of new calls per second per cell. CBP is the blocking probability of a new Class I calls and CDP is the dropping probability of new Class I calls. Bandwidth utilization is the rate of the bandwidth being used in the cell.

Figure 7 shows CBP of four mechanisms as the arrival rate of new calls increases from 0.01 to 0.1. According to the figure, the NR mechanism has the lowest CBP while ARMM has the next lowest. The reason for that is that the NR mechanism does not reserve bandwidth for hand-off calls and therefore has a larger amount of bandwidth available for new calls than other mechanisms. Because of the bandwidth reassignment scheme and adaptive bandwidth reservation method, the CBP of ARMM is nearly identical to that of the NR mechanism. Although the CBP of AR is lower than those of NR and FR, it is higher than that of ARMM. FR mechanism has a higher CBP than other mechanisms, because it does not adaptively reserve its bandwidth according to the network conditions.

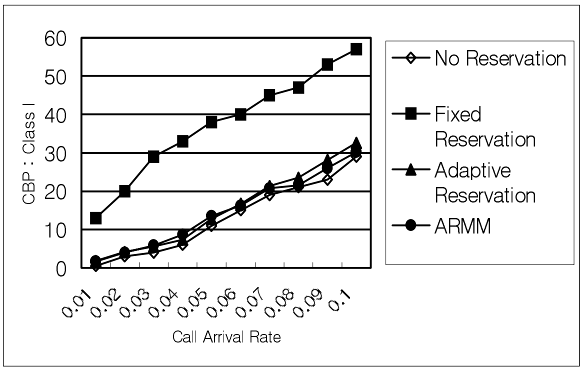

Figure 7. CBP : Class I

Figure 8 compares the CDP of each mechanism as the arrival rate of new call increases. ARMM has the lowest CDP while AR mechanism has the next lowest. The reason for that is because ARMM reserves bandwidth more adaptively than AR according to the network conditions through its 2-tier cell structure and MPP. The discrepancy in performance between ARMM and FR/NR becomes larger as the arrival rate of new calls increases, because ARMM reserves more bandwidth using the bandwidth reassignment scheme. The performance of AR is better compared to those of NR and FR, but is lower than ARMM. NR has the lowest performance because it does not reserve any bandwidth for hand-off calls. The CBP and CDP of ARMM is lower than those of AR.

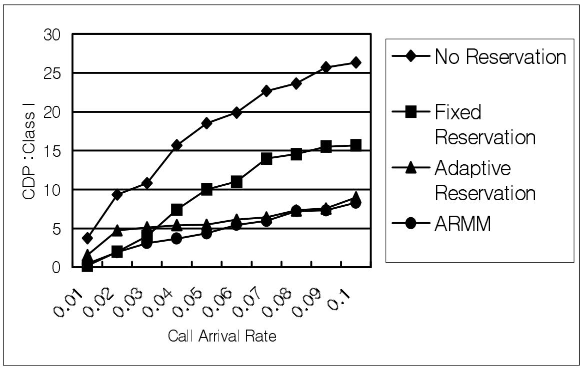

Figure 8. CDP : Class I

Figure 9 shows the bandwidth utilization of various mechanisms. NR has the highest bandwidth utilization while ARMM has the next highest. Because NR does not reserve any bandwidth in its neighboring cells for hand-offs, it has a high bandwidth utilization while ARMM has a higher bandwidth utilization than AR because it reserves a near optimal amount of bandwidth for hand-off calls through its 2-tier cell structure and MPP. FR has the lowest bandwidth utilization because it cannot adaptively readjust the amount of bandwidth for hand-off call.

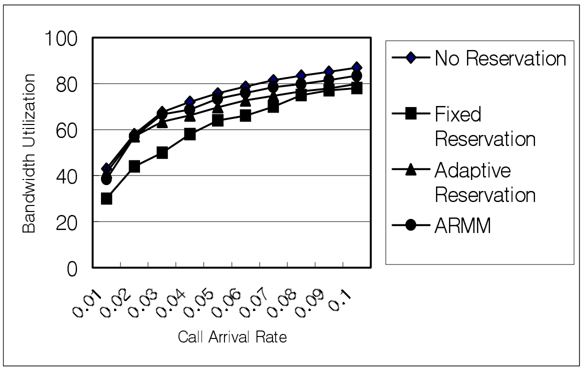

Figure 9. Bandwidth Utilization

From the above observation, we can conclude that the performance of each mechanism shows a trade-off between the CBP, CDP and bandwidth utilization. NR has high bandwidth utilization and a low CBP at the expense of a larger CDP than other mechanisms, because it does not reserve bandwidth for hand-off calls. FR has a lower CDP than NR, but has a higher CBP and lower bandwidth utilization than other mechanisms. ARMM has the lowest CDP of all the mechanisms, and also shows high performance in its CBP and bandwidth utilization. AR has a lower performance than ARMM all around. Therefore, we can conclude that the ARMM has a low CBP and CDP with the most effective bandwidth utilization compared to the other mechanisms.

We plan to evaluate our mechanism in more realistic environments with rapid changes in the arrival rate of new calls. [10] shows the various moving patterns of users according to the time of day. Table 6 shows the rapid time-varying change in the arrival rate of new calls.

Figure 10 to 12 show the results of the performance metrics based on the rapid change in the arrival rate of new calls illustrated in Table 6.

Table 6. Rapid Change of the Call Arrival Rate

Time (second)	1~ 2000	2001~ 4000	4001~ 6000	6001~ 8000	8001~ 10000
Call Arrival Rate	0.01	0.05	0.1	0.05	0.01

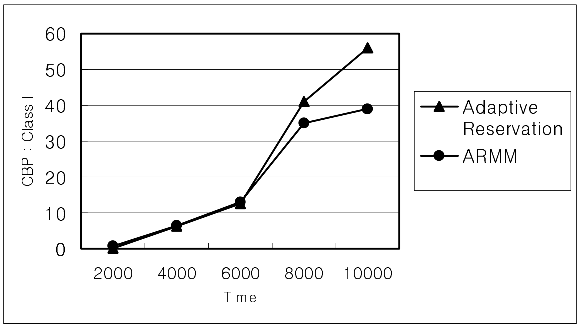

Figure 10. CBP Based on the Rapid Change of the Call Arrival Rate: Class I

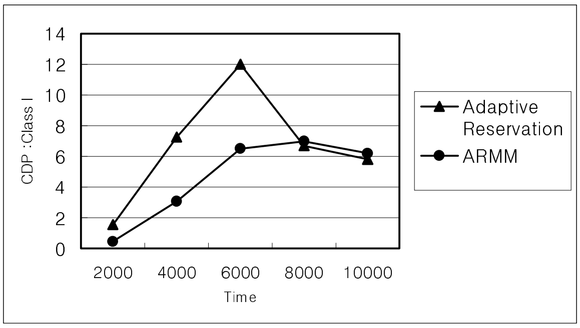

Figure 11. CDP Based on the Rapid Change of the Call Arrival Rate: Class I

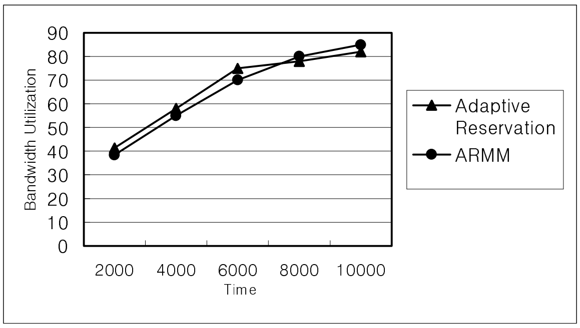

Figure 12. Bandwidth Utilization Based on the Rapid Change of the Call Arrival Rate

In a mobile computing environment with rapid changes of arrival rate of new calls, ARMM has a superior CBP and CDP compared to that of AR. It is because AR can only readjust the amount of reserved bandwidth by a pre-specified factor and thus cannot immediately readjust the amount in case of a rapid decrease in the arrival rate of new calls. For example, the CBP of AR is much larger than that of ARMM when the arrival rate changes from 0.1 to 0.05 and from 0.05 to 0.01. This is because AR reserves too much bandwidth for hand-off calls if there is a rapid drop in the arrival rate either from 0.1 to 0.05 or from 0.05 to 0.01 and thus increases the CBP. Because AR has too much reserved bandwidth for hand-off calls, its bandwidth utilization is lower than that of ARMM.

The CDP of AR is much larger than that of ARMM when the arrival rate increases either from 0.01 to 0.05 or from 0.05 to 0.1. This is because AR does not reserve enough bandwidth for hand-off calls if there is a rapid increase in the arrival rate either from 0.01 to 0.05 or from 0.05 to 0.1 and thus increases the CDP. Because ARMM reserves more bandwidth than AR to cope with the rapid increase of the arrival rate, its bandwidth utilization is lower than that of ARMM, although not by a significant amount.

The result of the simulation proves that ARMM dynamically better adapts the amount of reserved bandwidth than AR in a mobile computing environment with rapid changes of arrival rate of new calls.

5. Conclusions

For an optimal bandwidth reservation, we have proposed an adaptive bandwidth reservation mechanism based on MPP and a 2-tier cell structure. MPP is used to predict the next move of the client and the 2-tier cell structure is used to only apply the bandwidth reservation mechanism on clients with a high hand-off probability. In order to minimize the waste of bandwidth caused by an erroneous prediction, the bandwidth space reserved for hand-off calls was designed to be a common pool and the

QoS was classified into both a maximum and a minimum level.

We have compared the performance of three different mechanisms, “No Reservation”, “Fixed Reservation”, and “Adaptive Reservation”, have been compared through simulation.

Because the “No Reservation” mechanism does not reserve any bandwidth in its neighboring cells for hand-offs, it has high bandwidth utilization and low CBP, but has high CDP. Because the “Fixed Reservation” mechanism reserves a fixed amount of bandwidth, it has low CDP and high CBP. This mechanism also has the lowest bandwidth utilization because it cannot adaptively readjust the amount of bandwidth for hand-off call.

The “Adaptive Reservation” mechanism shows better performance than the above-mentioned mechanisms but still rates inferior to the ARMM.

The CBP and CDP of ARMM is always greater than those of AR by an amount of 5~10% and 8~50% respectively. The bandwidth utilization of ARMM is also greater than that of AR by about 5%. The difference in performance between the two mechanisms becomes even clearer when there is a rapid change of the arrival rate. The CBP and CDP of ARMM is greater than those of AR by an amount of 15~30% and 45~70% respectively. As a result, we were able to prove that ARMM has the best performance.

The ARMM may cause a message overhead between BS’s, bandwidth calculation overhead and a space overhead of clients. However, it is very important to efficiently manage the scarce-shared wireless networking resources. We have proven that the ARMM supports a consistent QoS, effective bandwidth utilization, low CBP and adaptively copes with a rapid change in the arrival rate of new calls. Due to such advanced performance, the ARMM proves to be effective in managing resources despite of the above mentioned overheads. A scheme to reduce the overhead caused by the bandwidth reservation mechanism, as well as a combination of a bandwidth reservation mechanism and a call admission control for more effective bandwidth utilization should be investigated in future works.

6. Acknowledgements

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References

[1] George H. Forman, and John Zahorjan, "The Challenges of Mobile Computing," *IEEE Computer,* April 1994.

[2] K. Lee, "Adaptive Network Support for Multimedia," *Proceeding MobiCom'95*, November 1995.

[3] K. Keeton, *et al.*, "Providing Connection-Oriented Network Services to Mobile Hosts," *Proceeding USENIX Symposium on Mobile & Location Independent Computing*, August 1993.

[4] C-K Toh, "A Hybrid Handover Protocol For Wireless ATM LANs," *ACM Journal on Mobile Networks & Applications*, Vol. 1 No. 3, December 1996

[5] S. Singh, "Quality of Service Guarantees in Mobile Computing," *Journal Computer Communications*, Vol. 19, pp. 359-371, 1996.

[6] S. Choi and K. G. Shin, "Predictive and Adaptive Bandwidth Reservation for Hand-Offs in QoS-Sensitive Cellular Networks," *Proceeding ACM SIGCOMM'98*, pp. 155-166, September 1998.

[7] C. Oliveira, J. B. Kim, and T. Suda, "An Adaptive Bandwidth Reservation Scheme for High-Speed Multimedia Wireless Networks," *IEEE JSAC*, Vol. 16, No. 6, August, 1998.

[8] Jay E. Padgett, Christoph G. Gunther, and Takeshi Hattori, "Overview of Wireless Personal Communication," *IEEE Communication Magazine*, Vol. 33, No. 1, January 1995.

[9] S. Lu and V. Bharghavan, "Adaptive Resource Management Algorithms for Indoor Mobile Computing Environment," *SIGCOMM*, September 1996.

[10] P.S. Hu and J. Young, 1990 NPTS databook: Nationwide Personal Transportation Survey, Federal Highway Administration, November 1993.

[11] S. Choi and K. G. Shin, "Bandwidth Reservation in Mobile Cellular Networks Using ITS Navigation Systems," *ITSC'99*, October 1999.