An Optimal Reservation-Pool Approach for Guaranteeing the Call-Level QoS in Next-Generation Wireless Networks

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Abstract. In order to provide the guaranteed mobile *QoS (Quality-of-service)* for arriving multi-class calls, we need to minimize the dropping rate of handoff calls while at the same time controlling the blocking rate of new calls. This paper proposed a new multi-class call admission control mechanism that is based on dynamically formed reservation pool for handoff requests. The simulation results show that the individual *QoS* criteria of multi-class traffic such as the handoff call dropping probability can be achieved within a targeted objective and the new call blocking probability is constrained to be below a given level. The proposed scheme is applicable to channel allocation of multi-class calls over high-speed multimedia wireless networks.

1 Introduction

Multimedia mobile communications are expected to be the dominant mode of access technology. Besides traditional voice communication, a new range of services such as multimedia, high-speed data, etc. are being offered for delivery over wireless networks. Mobility will be seamless for implementing the blueprint of person's being in contact anywhere and at any time [1-3]. *Mobile Quality-of-Service (M-QoS)* is a set of performance parameters associated with wireless link such as channel error rate and with mobile units such as *Handoff-call Dropping Probability (HDP)* and *New-call Blocking Probability (NBP).* In order to provide higher capacity on the limited radio spectrum, we should use smaller-sized cells such as *pico-* cells instead of *macro-* or *micro-* cells. For such a small cell size, handoff will occur more frequently and make *HDP* a crucial consideration in *M-QoS*. Such handoffs involve allocating sufficient resources in each arriving cell to maintain the *QoS* needs of the established connections. It is a common practice to give a higher priority to the handoff calls as compared to new calls. On the other hand, giving too much priority to handoff calls will result in an excessive *NBP*. Denying of too many new calls can bring an unacceptable ratio of carried-to-admitted traffic and a unsatisfactory revenue for network providers. Various channel allocation schemes have been proposed to implement handoff prioritization and at the same time not hamper the acceptance of new calls.

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Most of the papers in the literature assume single-class traffic in the cells. The provision of multi-class services (also called multimedia communications) is gaining wide acceptance and will be more ubiquitous in the future wireless and mobile systems.

1.1 Related Works for Multi-class *CAC*

Recently limited work has been reported in the literature regarding CAC schemes in multi-class wireless networks [12-18,20]. In this section we review four different multi-class *CAC* mechanisms which have been proposed in the literature [10,16,18,20].

S. K. Das *et al.* [20] developed an integrated framework for *QoS* provisioning at a lower layer such as the radio link layer combining a novel *CAC* strategy. In this paper we will refer to their scheme as *Low Layer Control Scheme (LLCS). LLCS* can adapt to time-varying and high *Bit Error Rate (BER)* feature of wireless physical link. *LLCS* performs *CAC* on the basis of channel reservation. *QD* in [17] is extensively used in situations where call demands exceed the network's capacity. *LLCS* covers the entire *Network-QoS* which involves multiple layers. Therefore it does not focus on implementation details of channel reservation and handoff prioritization. In our scheme, we adopt the concept of reservation pool for handoff request reservation. This idea is based on increasingly accurate position predicting technology instead of simple *MH* classification and destination determination among three neighboring cells in [20]. This improvement means that we can further reduce the over-reserving of wireless bandwidth. Another *CAC* scheme based on adaptive bandwidth reservation has been proposed by Oliveira et al. in 1998 [16]. We refer it to as *Oliver98* scheme. One of the drawbacks of *Oliver98* strategy is that handoff prioritization, a crucial component of *CAC* mechanism, is based on the concept of *Quality Degradation (QD). QD* should be equally used for all kinds of calls instead of only handoff calls. Another drawback of *Oliver98* strategy is that all of their simulations assume the inter-arrival times of handoff / new calls to follow a geometric distribution, which cannot reflect the actual traffic conditions [18]. The best assumption is general distribution.

Another scheme which we refer to as *Potential Resource Estimation Scheme* (*PRES*) is proposed by Ramanathan in [18]. The obvious drawback of *PRES* is that it shows extremity for handoff prioritization. Handoff prioritization means that we should give handoff calls much higher priority over new calls[1]. However, it does not imply that we should accept all of the handoff calls and consider only the admission control of each arriving new call. If *PRES* is used in practical systems, it may bring unacceptably high *NBP* while minimizing *HDP*. This may lead to network providers' unhappiness due to low revenue resulting from low carried traffic.

One Step Prediction Scheme (*OSPS*) was suggested by Epstein in [10,12-14]. This approach predicts the amount of bandwidth needed in the current cell and each of the

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[1] In typical cases, the value of *HDP* is within the range of 10^{-5}~10^{-2}, and the value of NBP is within the range of 10^{-3}~10^{-1}. In other words, *HDP* is generally *100* times larger than *NBP* in the system.

neighboring cells for a specified time interval ahead (called One Step) when a new call of any class arrives. One of the drawbacks of *OSPS* is that it assumes the MH will handoff to all neighboring cells with equal probability when estimating One Step bandwidth. It overestimates the required bandwidth in those neighboring cells and unnecessarily denies many new calls, which makes the *NBP* unacceptably high when *OSPS* is applied to practical *WATM* networks.

1.2 Contributions to Multi-class *CAC* Mechanism

The first contribution to multi-class *CAC* mechanism is that we give a detailed and practical framework for handoff requests reservation. Our discussion assumes an *accurate* next-cell prediction scheme. With the successful application of Kalman filter to *Global Position System (GPS)* and other position locating systems, a precise next-cell prediction technology will become a reality in the next generation mobile networks. It is unnecessary to assume the *MH* will handoff to neighboring cells with undeterminable probability such as in *Oliver98* strategy. It is also incorrect to regard the probabilities to all neighboring cells as the same value such as in *OSPS*. The timing relationship is analyzed between handoff request reservation and later handoff call admission. This is very meaningful for practical system implementation. The state transition map is given for our reservation pool mechanism.

Secondly, for guaranteeing the *M-QoS* of each class of handoff calls, we propose a new notion of *Reservation Ordering (RO)* of handoff requests. *RO* is about the assigning of admission priorities for multi-class calls. However, our admission priority determination is made according to the *MH's* time-varying movement behaviors and the desired *M-QoS* requirements of the multi-class calls themselves. On the other hand, *OSPS* determines call priorities based on only calls' *M-QoS* profiles. For the computation of *RO* value, a weighted algorithm is proposed.

Unlike *LLCS* and *Oliver98* strategy, we assume many traffic classes instead of just two classes (*real-time* and *non-real-time*). The desired amount of bandwidth and delay requirements for these *QoS* profiles can vary greatly. Although *PRES* and *OSPS* also assume multi-class traffic, we analyze urgency details of different *ATM AAL* services instead of simply assuming *K* classes of mobile users. Such urgency details are used for computing *RO* value.

Channel shuffling is our modification of bandwidth compression which is proposed in [20]. Because our channel assigning mechanism involves accurate *MH* identification between handoff request reservation and handoff call admission, we should carry out the shuffling of reservation channels and unoccupied channels at the same time.

Our *CAC* approach is implemented in a distributed way. The algorithm needs only the signaling information between local *BS* and *MH*. This method can bring reduced computation load compared to *MSC*-centered control policy.

Table 1 shows the comparisons between the features of our proposed scheme and those of other four schemes.

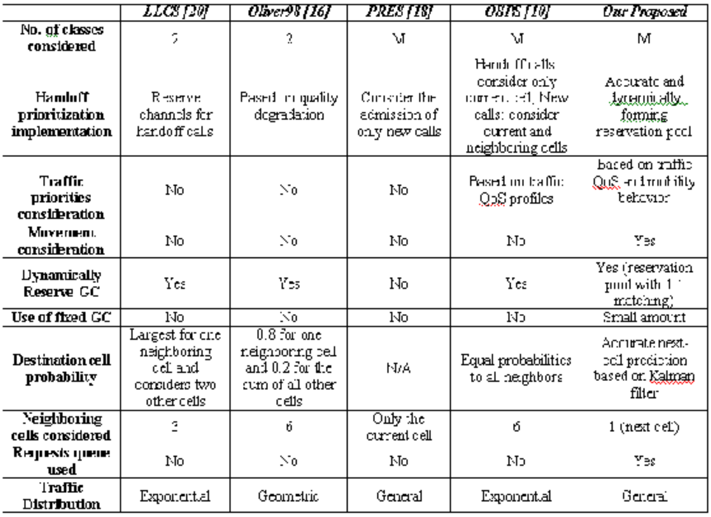
The rest of this paper is organized as follows. Section 2 describes the detailed procedure for forming handoff request reservation pool which is based on accurate next-cell prediction. This is followed by the presentation of *RO* policy in Section 3. Section 4 provides our simulation results and corresponding analysis. Finally, we conclude the paper with a discussion of further work in Section 5.

2 Multi-class Bandwidth Resource Reservation

2.1 Next Cell Prediction

Most of the existing mechanisms for bandwidth reservation and allocation of handoff / new calls assume that we can get the mobility pattern of the *MH* using profile-based schemes. This assumption may not be valid for practical systems. For example, in wireless ATM network environments, wireless components can be connected to *Wide Area Network (WAN), Local Area Network (LAN)* or even Home depending on what kind of ATM network is to be accessed. For such varied wired networks, it may not be possible to predict the arrival of *MH* to some cell since the mobility patterns may not be available. Another drawback for profile-based schemes is that varying traffic conditions suggest that such history-based schemes can never be fully reliable. Therefore we should use real-time position measurements to predict the future path of a moving *MH*. The greatest advantage of future position prediction is that we can determine the next cell which the *MH* will cross with high accuracy. Therefore we need to reserve wireless resources only in next cell among all of the neighboring cells and eliminate the reservation of excessive bandwidth in those neighboring cells where the sum of arriving probabilities is less than some small value. Taking into consideration the limited radio resources compared to wired part of wireless network, such an advantage is valuable. *GPS* can estimate the location of a *MH* with a *95%* probability level within a *100m* margin. However, if differential *GPS* is employed, we can even achieve *3-5m* margin [6].

Table 1. Comparisons of different schemes



	LLCS [20]	*Oliver98 [16]*	*PRES [18]*	*OSTS [10]*	*Our Proposed*
No. of classes considered	2	2	M	M	M
Handoff prioritization implementation	Reserve channels for handoff calls	Based on quality degradation	Consider the admission of only new calls	Handoff calls consider only current cell, New calls: consider current and neighboring cells	Accurate and dynamically forming reservation pool
Traffic priorities consideration	No	No	No	Based on traffic QoS profiles	based on traffic QoS and mobility behavior
Movement consideration	No	No	No	No	Yes
Dynamically Reserve GC	Yes	Yes	No	Yes	Yes (reservation pool with 1:1 matching)
Use of fixed GC	No	No	No	No	Small amount
Destination cell probability	Largest for one neighboring cell and considers two other cells	0.8 for one neighboring cell and 0.2 for the sum of all other cells	N/A	Equal probabilities to all neighbors	Accurate next-cell prediction based on Kalman filter
Neighboring cells considered	3	6	Only the current cell	6	1 (next cell)
Requests queue used	No	No	No	No	Yes
Traffic Distribution	Exponential	Geometric	General	Exponential	General

2.2 Determining the Time of Multi-class Handoff Requests Reservation

In this paper, we give a practical way to determine the *Reservation Deadline (RD)* which is a time instance by which bandwidth assignment for the arriving handoff call should be completed. To avoid blind selection of the start point of channel reservation for handoff requests, we define the concept of *Core Area (CA)* with a radius of size *Threshold Distance (TD)* in the current cell as shown in Fig. 1 (Right). In *CA,* there is a high probability for the *MH* to make a dramatic change in its direction and speed. The similar idea is proposed in [6,7]. However, if *MH* moves beyond *CA*, the chances of sudden change of direction are reduced. Thus we can improve the accuracy of next-cell prediction by using Kalman filter. The reasonable position to start making reservations can be chosen as *O* shown in Fig. 1 (Right). From the point of view of *RSS,* position *O* corresponds to the value of *RSS1* in the current cell in Fig. 1 (Left). The relationship between the *RSS* and distance *x* from the transmitter of the *BS* is [19]:

$$RSS_{dB} = -10\gamma \times Log(x) \tag{1}$$

where γ is the propagation path-loss coefficient.

To determine the value of *RD*, we consider the following two criteria:

(1) The *RSS* level of current *BS* drops below a threshold *RSS2* so that it is somewhat difficult to keep the communication with *MH.* The position corresponding to *RSS2* is shown as *A* in Fig. 1 (Right).

(2) The *RSS* level of next-cell *BS* is stronger than that of the current *BS* by a given hysteresis margin Δ. That is, we can only serve handoff calls within the shaded *RSS* range of Fig. 1 (Left).

As can be seen from Fig. 1 (Left), the *RSS* level meeting condition (1) is on the right of line *A*, while for meeting condition (2) is on the right of line *B*. Thus, to meet both conditions, we have to choose right of line *B.* Therefore, once a *MH* arrives at position *B*, we should stop the submitting of handoff request immediately. Then the reservation *Time Duration* Ω for a *MH* is from arriving time at position *O* to arriving time at position *B*. Ω can be expressed as:

$$\Omega = \mathrm{T}_{OB} = t_B - t_O \qquad \text{2)}$$

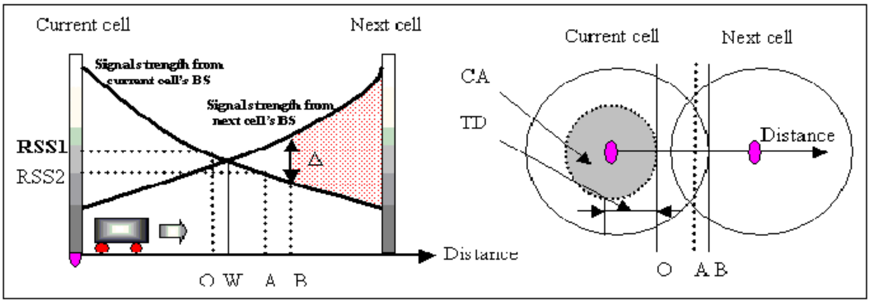


Fig. 1. Time for forming reservation pool (between O and *A*) (Left) *RSS* point of view (Right) Geometry point of view

If we consider predominantly walking and stationary users with an average speed of *2m/s* and a cell radius of *300m*, which is a common case is wireless ATM campus LAN, the typical value of Ω is about *5s ~ 15s* [19]. The value of Ω is important since all of the handoff reservation actions, such as *RO* and overflow request queuing *RO* which will be discussed later, should be finished during Ω. Also the values of *QDT* and *RET* (discussed in Section 5) are setup based on the value of Ω.

2.3 Forming of Multi-class Reservation Pool

Each handoff *MH* sends their bandwidth requirements to the *BS* of next-cell during their own Ω. These handoff request reservations will form a varied-sized pool through marking unoccupied channels from *Free* to *Reserved*. As shown in Fig. 2, handoff calls of different classes can reserve highly varying sized *Channel Blocks (CB)*. The term *CB* comes from the fact that in normal case a handoff call belonging to some class will occupy a series of allocated time slots. The sizes of *Free* and *Occupied* bands are also varying since at any time there are always occupied channels released due to calls completion or handoff to another cell. the dark-shaded channel band is marked as *GC (Guard Channels).*

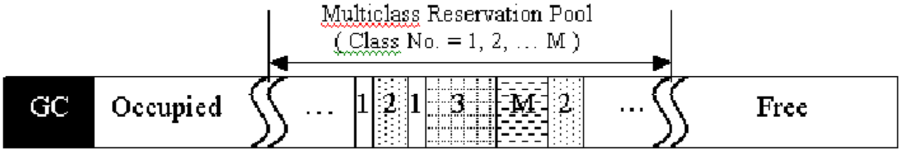


Fig. 2. A snapshot for the channels' status in the current cell

We can draw the *State Transition Map (STM)* as shown in Fig. 3.

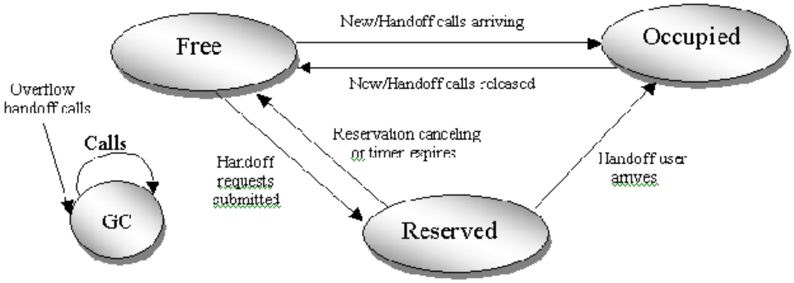


Fig. 3. States Transition Map for the channels with respect to time

3 *Reservation Ordering (RO)* for Multi-class Handoff Calls

The challenging task of bandwidth assignment for multi-class calls is that we should take into consideration largely different *QoS* profiles of each class such as *HDP*, latency tolerance and desired amount of *W-EB*. For multi-class calls, we should assign each class of calls different priorities during resource allocation, unlike in single class case where all calls are assumed to have the same priority. The role of *Reservation Ordering (RO)* is to make sure that the service order for each submitted handoff request reservation is maintained.

For determining the *RO* priority for serving each handoff call, we define a term *Class Urgency (CU)* which represents the desired serving urgency degree. *CU* of the coming multimedia calls is determined by their *M-QoS* parameters such as delay tolerance and *HDP*. However, *CU* cannot be used as the only factor for determining the value of *RO*. For example, when a *MH* is moving almost beyond *reservation area* (from position *O* to position *B* in Fig. 1 (Right)), possibly we should serve this handoff call immediately even though its *CU* is low since its *RSS* from the old *BS* is too weak to continue the communications. In other words, the *RSS* value can become another factor for determining the *RO* priority.

Varying speeds of *MH* can be a serious problem in *WATM* environment where very rapid fading is common due to its small cell size and low used power. To make the situation worse, the *MH* in *reservation area* can wait in traffic jams, traffic lights, or at stop signs. For these cases, it is very improper to assign these *MH* higher priorities just because their *RSS* is low. Since *MH* can travel at different speeds and directions, a faster *MH* will generally require an earlier handoff than a slower one. Thus *MH* velocity can become another important factor for determining the *RO* priority. We can define the *RO* priority as a two-level weighted scheme:

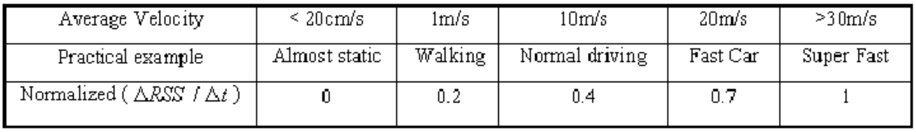
$$RO = \left[W_1 \times (\Delta RSS / \Delta t) + W_2 \times (RSS) + W_3 \times (Class\ \ Urgency)\right] / 3 \qquad (W_1 + W_2 + W_3 = 1) \tag{3}$$

where $\Delta RSS / \Delta t$ reflects the value of *MH* velocity, and *RSS* determines the distance of *MH* from its *BS* as shown in formula (3). In multi-class network, we can assign $W_1, W_2, and\ W_3$ based on the significance which above-mentioned three factors may have on *RO*. A reasonable weight suite assignment is:

$$W_1 = 0.1, W_2 = 0.4, \ and \ W_3 = 0.5 \tag{4}$$

Since *CU* plays such an important role in multimedia network. Note that we should normalize the value of $\Delta RSS / \Delta t$ and *RSS* between *0* and *1*. Table 2 shows a possible velocity normalization.

Table 2. A possible velocity normalization result



Average Velocity	< 20cm/s	1m/s	10m/s	20m/s	>30m/s
Practical example	Almost static	Walking	Normal driving	Fast Car	Super Fast
Normalized ($\Delta RSS / \Delta t$)	0	0.2	0.4	0.7	1

Note that *RO* depends on two factors. One is *CU* of handoff calls which is only determined by defined *QoS* class. The other is varying mobile behaviors of *MH*. We use velocity ($\Delta RSS / \Delta t$) and position *(RSS)* to symbolize the latter factor. This scheme is different from *OSPS* where calls priorities are only determined by class *QoS* parameters.

There are already many good ways for measuring *MH* velocity such as in [7,8,9,19]. Thus it is not difficult to obtain the value of $\Delta RSS / \Delta t$.

The following pseudo-code describes the necessary system operations each time a *MH* handoff request message is sent to the next-cell's *BS*.

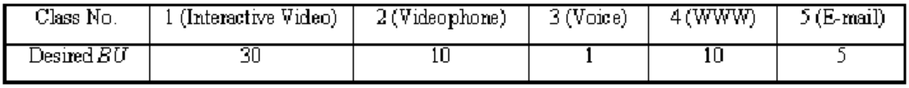
```
Using (7) to compute RO for that MH
   IF this message is a Reservation Canceling
{Re-mark the channels for that MH from 'Reserved' to 'Free' in the pool;
  Delete the buffer unit for that MH in the Reservation Queue if it exists;}
  Else IF this message is a Reservation Confirming_
  IF there is already a 'Reserved' CB for that MH in the pool
      {Modify its RO to the new value;
  Reorder all the CB based on their new RO value in the pool;}
      Else    /* This is a new reservation */
  {Delete the buffer unit for that MH in the Reservation Queue if it exists;
   IF available free bandwidth ≥ Desired bandwidth
   {Insert a new CB in the reservation pool based on RO priority}
  Else    /* available free bandwidth < Desired bandwidth */
  {Buffer it into the Reservation Queue}♣
```

4 Simulation Experiments

4.1 Simulation Model

Based on the proposed *CAC* algorithm we built a C-based simulator. In this simulation we choose the total capacity of the current cell as *10,000*[3] *Bandwidth Units (BU).* The *BU* requirements for the five classes of calls are chosen as shown in Table 3.

Table 3. *BU* requirements for the five classes



Class No.	1 (Interactive Video)	2 (Videophone)	3 (Voice)	4 (WWW)	5 (E-mail)
Desired *BU*	30	10	1	10	5

The cell radius is assumed to be *500m,* which is a typical size for future *WATM* system. Three different velocities are assumed: *2m/s* (walking), *10m/s* (normal-speed car), and *20m/s* (high-speed vehicle). Furthermore we assume that the five classes of

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[3] In this simulation, we choose this capacity value only for testifying the effect of our scheme. As a matter of fact, future *WATM* or even *IMT-2000* should be expected to be able to provide an aggregate transmission capacity of *25 Mb/s* when such systems are offered at frequency bands above *3 GHz*.

calls have the same percentages of three velocities in order to emphasize the influence of *class urgency* on the computation of *RO*. A cluster of seven cells is assumed and each cell keeps contact with its six neighboring cells.

4.2 The Role of Queue

Our approach uses a queue for storing overflowing handoff reservations due to the lack of *free* channels. To investigate the effect of the queue, we assume the same numbers of five class of handoff requests, that is, their percentage within the total handoff requests is *20%* individually. Because handoff congestion happens only when *HTL* is high, we let *HTL = 80%,* which makes the *HDP* almost ten times larger than the *HTL = 50%* case.

The *HDP* results of five classes of handoff calls are shown in Fig. 4. Although each class of handoff calls experience a certain degree of improvement for their *HDP* due to the introduction of reservation queue, the improvement values are different. It can be seen that *class 5* calls have the most dominant decreasing *HDP* while *class 1* calls have the least improvement compared to *no queue* case. A possible explanation for this phenomenon is that *class 5* calls have the lowest serving priority among the five classes of calls since only *Class Urgency* is crucial for computing the value of *RO* after the elimination of other factors such as mobile movements. Since the percentage of *class 5* users is the same as other classes, *class 5* calls will have the largest probability for being buffered into reservation queue. Therefore they benefit the most from reservation queue.

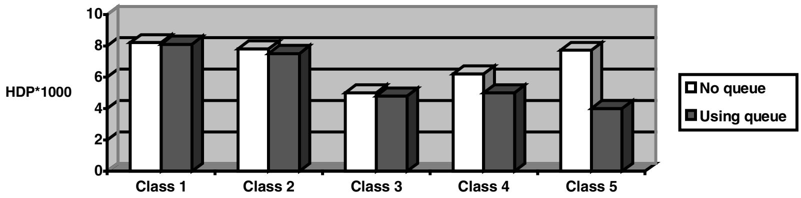

Fig. 4. The importance of reservation queue

4.3 The Importance of Determining Multimedia Servicing Prioritization

If we assume that *MH's* position and velocity cannot influence much on the *RO* of each handoff call except for the *CU* of each class[4], we can see the effect of *RO* on improving *HDP* of each class of handoff calls.

We only consider two classes of calls: *class 1* and *class 5*, since *class 1* calls have the most crucial urgency requirements while *class 5* calls have the least urgency requirements. Two important cases are considered: light handoff load *(HTL = 25%)* and

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[4] This can be done by assuming each class of calls have the same percentage of all types of moving users such as pedestrians and cars.

heavy handoff load *(HTL = 75%)*. The reason for choosing these two extreme cases is that we may see the effect of *RO* on *HDP* more clearly.

Figure 5 (a) ~ (d) are our simulation results. The *X-axis* represents the percentage of a given class of calls among all handoff calls. It varies from *20% to 100%*. The *Y-axis* is the value of *HDP* multiplied by *10,000*. It can be seen that *HDP* of *Class 1* calls decreases when *RO* is adopted. Although in light handoff load case, the reduction is not very obvious (Fig. 5 (a)), in heavy handoff load case the effect of *RO* is very dominant (Fig. 5 (b)). This is not a surprising result since *RO* can assign *class 1* calls the highest priority when only *CU* is considered.

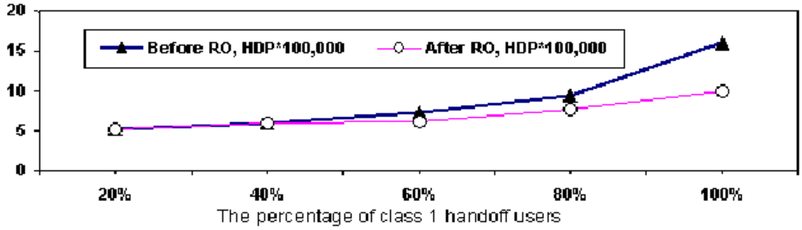
Unfortunately, *HDP* increases for *class 5* calls (Fig. 5 (c) and (d)), especially in heavy handoff load case (Fig. 5 (d)). This is because *class 5* calls get the lowest priority when their *RO* is compared to other classes. When the network is under congestion, the *class 5* calls have the highest probability for being dropped among the five classes.

For dealing with this problem, we can use the crossover ATM switch to buffer those delay-insensitive *class 5* ATM cells. When the handoff connection is rerouted from the old path to a new path, a crossover switch should be found out using fast searching algorithm [5]. Thus, the down-link data stream can be stored in the buffer of this switch.

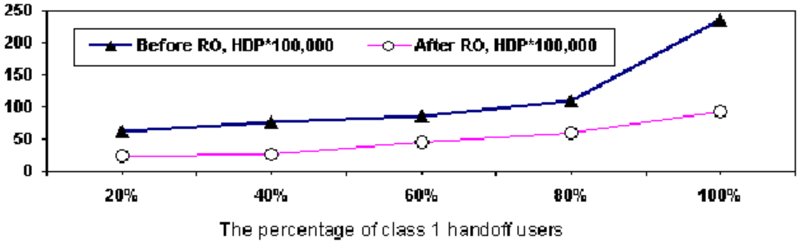
5 Conclusions and Future Work

This paper addressed the problem of providing *M-QoS* guarantee for multi-class calls in the *WATM* network. The network is assumed to be able to accurately predict next-cell which the *MH* will cross. This assumption is reasonable for the developing mobile position system such as *GPS*. A multi-weighted algorithm for computing priorities of handoff requests was proposed in order to serve arriving multi-class calls with highly diverse *QoS* parameters. A dominant feature of our approach is combining practical handoff behaviors with the call admission procedure. This includes the *RO* computation and the notion of three timers. Several important considerations for practical system implementation were discussed in this paper.

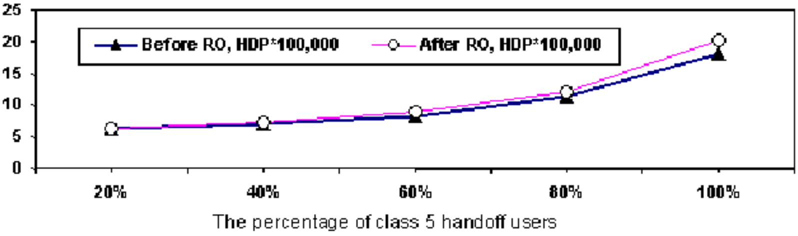
In the introduction of this paper we mentioned that we focus on the *LCA* mechanism instead of *CCA* mechanism. However, there is close relationship between these two mechanisms. A typical example is *Channel Borrowing Mechanism (CBM)* [4]. *CBM* states that the whole capacity of any cell is not a fixed value. Each cell only keeps a set of nominal channels (less than *FCA* case) and can borrow free channels from its neighboring cells to accommodate new calls. Thus, the *NBP* can be further decreased. One of our future tasks is combining the *CBM* with our proposed approach to investigate the improvement of *NBP*. Another future task is to derive analytical models to evaluate the performance of our *CAC* scheme. As shown in Fig. 1, this paper provides a reservation-based call admission strategy for guaranteeing the network *QoS*. Further work in this area will include translating the high-level resource allocations into scheduling at the low levels such as *MAC* layer so as to map the network *QoS* to *MAC-oriented QoS*.



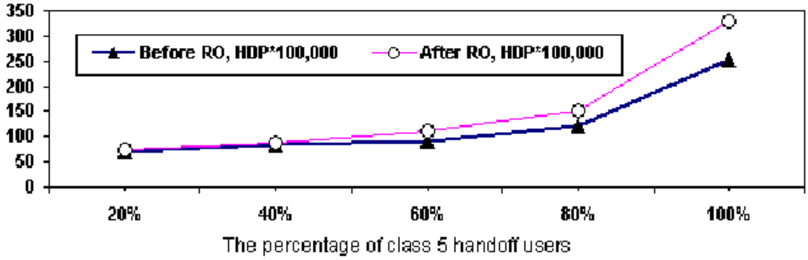
(a) *HDP×100,000* for *Class 1* with *HTL* = 25%



(b) *HDP×10,000* for *Class 1* with *HTL* = 75%



(c) *HDP×100,000* for *Class 5* with *HTL* = 25%



(d) *HDP×100,000* for *Class 5* with *HTL* = 75%

Fig. 5. The influence of *RO* on *HDP*

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