# Efficient Call Admission Control for Heterogeneous Services in Wireless Mobile ATM Networks

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## ABSTRACT

An efficient call admission control scheme for handling heterogeneous services in wireless ATM networks is proposed. Quality-of-service provisioning of jitter bounds for constant bit rate traffic and delay bounds for variable bit rate traffic is used in the CAC scheme to guarantee predefined QoS levels for all traffic classes. To reduce the forced handoff call dropping rate, the CAC scheme gives handoff calls a higher priority than new calls by reserving an appropriate amount of resources for potential handoff calls. Resource reservation in the CAC scheme makes use of user mobility information to ensure efficient resource utilization. Simulation results show that the proposed CAC scheme can achieve both low handoff call dropping rate and high resource utilization.

## INTRODUCTION

Wireless asynchronous transfer mode (ATM) networks are the internetworking of wireline ATM networks and wireless cellular networks. They are broadband wireless networks capable of providing adequate multimedia service support for mobile users anywhere at any time. This implies that wireless networks should provide packet-based transport and bandwidth on demand, as well as support multimedia applications. The integration of wireline and wireless networks poses significant challenges because of user mobility, limited radio frequency spectrum, radio channel impairment, and so on in the wireless segment.

To efficiently utilize the limited radio spectrum and maximize system capacity, the cell size of future wireless ATM networks tends to be small. As a result, a mobile user's connection may have to be handed off from one serving base station (BS) to a neighboring BS several times during the entire connection period.

Handoff calls should be assigned higher priority than new calls, because the interruption of an ongoing call is much more undesirable than refusing to admit a new call from the users' point of view. To guarantee an uninterrupted connection for a call during its entire lifetime, different resource reservation schemes have been proposed to allocate part of the network resources for potential handoff calls. A virtual connection tree (VCT), consisting of a group of preestablished connections between a fixed switch and a set of BSs, to serve mobile users is proposed in [1]. A mobile can freely hand off to any cell within the VCT without being subject to new admission control. Admission control for homogeneous traffic is considered in [1]. A distributed call admission control (CAC) procedure is proposed in [2], which makes admission decisions for new calls taking into consideration the potential handoff calls in order to keep forced handoff call dropping rate low. It is performed at each BS in a distributed manner, and only homogeneous traffic is considered. A shadow cluster concept is proposed in [3]. A *shadow cluster* is a set of BSs a mobile may influence in the near future and moves along with the mobile. The shadow cluster concept together with user mobility information are used in the CAC scheme in [3] to predict the resource demand in the near future and reserve resources accordingly. The CAC scheme presented in [4] allocates the required resources for a call in its current cell and adaptively reserves resources in all the neighboring cells for it. The amount of reserved resources is determined by the quality of service (QoS) requirements of the call and the current traffic load of the network, and adjusted dynamically.

In general, admission decisions in wireless ATM networks are made to ensure guaranteed QoS for heterogeneous traffic, while maintaining high resource utilization and low handoff call dropping rate. To achieve this, a BS must maintain a balance between the two conflicting requirements: to maximize resource utilization and minimize the forced handoff call dropping rate. In order to maintain the maximum resource

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utilization, the maximum number of calls should be admitted into a network, which may result in unacceptably high handoff call dropping rates due to insufficient resources for handoff calls. Therefore, it is very important in wireless ATM networks to develop a dynamic CAC scheme which can estimate future resource demands, reserve the minimum amount of necessary resources to maintain an acceptable handoff call dropping rate, and provide relatively high resource utilization.

User mobility information, which is the probability that a mobile user will reside in a particular cell at future moments, is the key information to obtain accurate estimation of resource demands at future moments. Except for [3], none of the above-mentioned CAC schemes considers individual user movements in wireless networks. Inaccurate knowledge or lack of user mobility information may result in inaccurate resource estimation, which would further lead to underutilizing or overloading the available network resources. In the former case, some calls that otherwise should be admitted may be rejected, while in the latter case, the handoff call dropping rate may be unacceptably high.

In this article a distributed CAC scheme is proposed for wireless ATM networks, which statistically multiplexes user mobility information to estimate future demand and available resources. Resource reservation for potential handoff calls is dynamically adjusted according to the user mobility information to meet the QoS requirements for heterogeneous traffic. With a nonpreemptive priority polling protocol [5], the proposed admission decisions are based on the developed jitter bounds for constant bit rate (CBR) traffic and delay bounds for variable bit rate (VBR) traffic [6].

The remainder of this article is organized as follows. We briefly describe the system model of the nonpreemptive priority polling scheme, followed by improved jitter bounds for CBR traffic and delay bounds for VBR traffic. We then present the proposed CAC scheme in detail. Simulation results are given, followed by conclusions.

## THE SYSTEM MODEL

Consider a wireless mobile ATM network where several BSs are connected to an ATM backbone network through a mobile switching center (MSC). The multiple access mode used is time-division multiple access (TDMA). Each BS can support different types of traffic. This work is confined to the coverage area of one MSC. The wireless system is characterized by a broadcast channel in the forward direction (or downlink), where the BS is capable of broadcasting packets to all users, and a multiple access channel in the reverse direction (or uplink), where all users are capable of sending packets to the BS. In the remainder of this article, we focus on the uplink channel and assume that two or more packets sent by different users at the same time will collide and be lost.

We consider three types of ATM traffic: CBR, VBR, and available bit rate (ABR). As shown in Fig. 1, all CBR calls in a system can be divided into $N_c$ CBR classes, indexed by $i = 1, 2, \ldots, N_c$; and there are $n_i$ CBR calls with the same parameters $(\gamma_i, \delta_i)$ in the $i$th CBR class, where $\gamma_i$ is the packet generation rate and $\delta_i$ is the delay variation (jitter) tolerance. All VBR calls in a system can be divided into $M_v$ VBR classes, indexed by $j = 1, 2, \ldots, M_v$, and there are $m_j$ VBR calls with the same parameters $(\rho_j, \sigma_j, d_j)$ in the $j$th VBR class, where $\rho_j$ is the average packet generation rate, $\sigma_j$ is the burst tolerance, and $d_j$ is the maximum tolerable transit delay. An ABR call has no delay or delay variation specification, and its minimum packet rate (MPR) is set to zero.

Each call in the $j$th VBR class is also regulated by a leaky bucket (LB) with parameters $(\rho_j, \sigma_j)$ at the BS, where $\rho_j$ corresponds to the BS polling token (PT) generation rate, and $\sigma_j$ the BS PT buffer size.

Different priorities are given to different traffic classes according to their QoS constraints. CBR traffic is given the highest transmission priority, ABR traffic the lowest. Within the CBR traffic, the classes with smaller jitter tolerance are given higher priority. Within the VBR traffic, the classes with smaller delay tolerance are given higher priority. All the ABR calls share the remaining resources in a fair and efficient manner.

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Packet transmission is directed by the BS according to the preset priority. It is assumed that there is a separate control channel for signaling. Each call has one ready-to-transmit (RTT) buffer located at the mobile station. Upon generation, all the packets are temporarily stored in their RTT buffers. The execution of the multiple access scheme adheres to the following rules [5]:

- For a call in the $i$th CBR class, its PT is generated every $1/\gamma_i$ s at the BS.
- For a call in the $j$th VBR class, its PT is generated every $1/\rho_j$ s at the BS and is stored in the BS PT buffer.
- Whenever the channel is cleared, the BS scans the PT buffer for CBR classes from the highest priority to the lowest. If a PT is found, the BS removes the PT and polls the CBR class.
- If there is no PT for all CBR classes at this time, the BS continues to scan the PT buffer for VBR calls according to the preset priority. If a PT is found, it removes the PT and polls the VBR class.
- When there is no PT found for CBR and VBR classes, the BS begins to serve ABR calls.
- Within each class, the calls are served by a round-robin scheme.
- Every time a call is polled, it transmits at most one packet from its RTT buffer.

The details of the polling scheme can also be found in [5]. A variant of the polling scheme, with LB control of VBR traffic residing in the mobile station, and in which each CBR and VBR class has only one call, is considered in [6].

## QOS PERFORMANCE BOUNDS OF CBR AND VBR CALLS

In this section the QoS performance bounds of CBR and VBR calls will be derived. For simplicity, it is assumed that all the data packets have the same length, and there is no transmission error. Let $\tau_p$ and $\tau_d$ be the time to poll a call and

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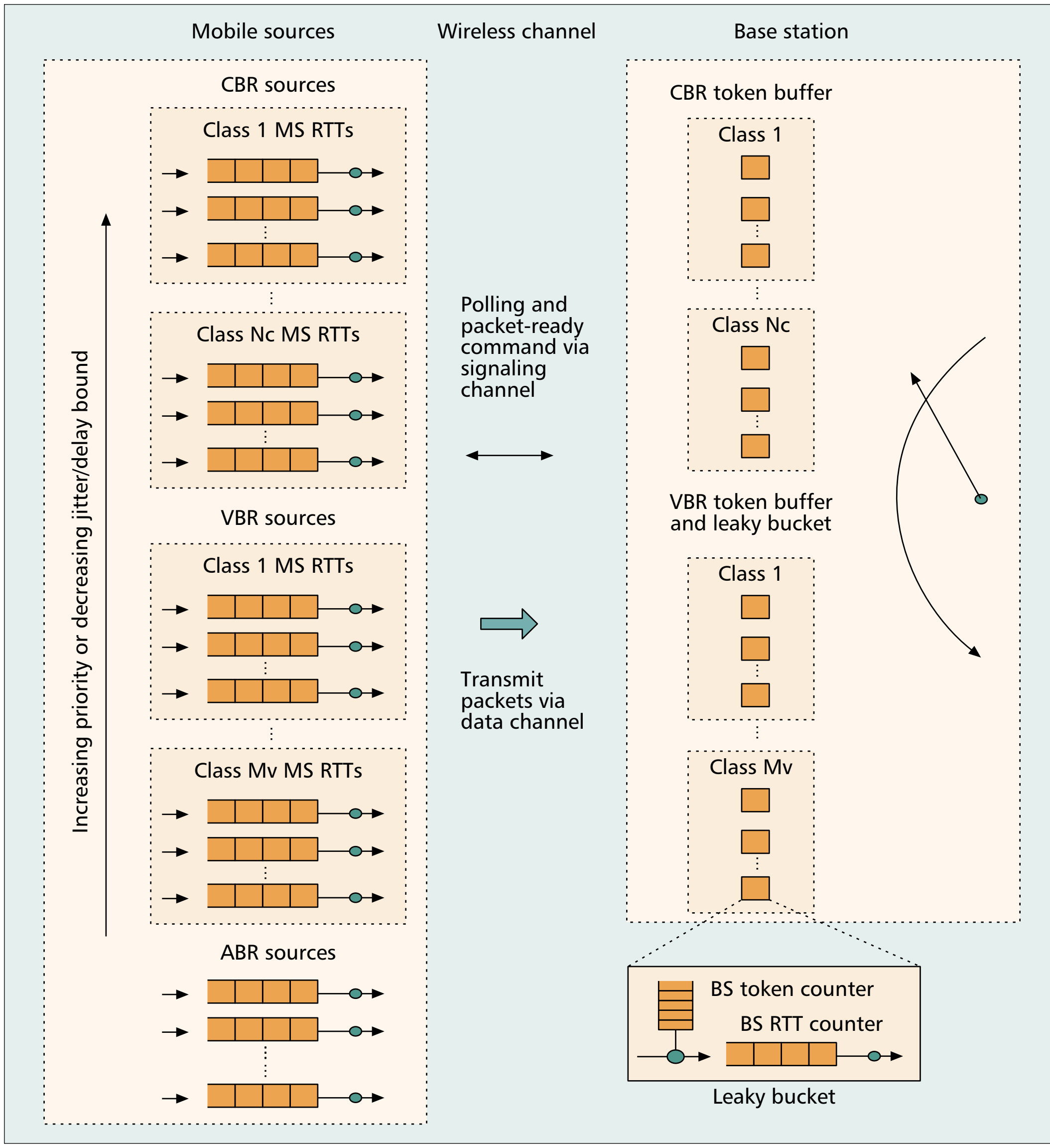


**Figure 1.** *A system model of a polling scheme with nonpreemptive priority.*

transmit a data packet, respectively, and $a = \tau_p + \tau_d$. The following theorems provide sufficient conditions to satisfy the performance bounds of all CBR and VBR calls.

*Theorem 1*: Let

$$\delta_i' = \frac{\sum_{k=1}^{i} n_k}{\frac{1}{a} - \sum_{k=1}^{i-1} n_k \gamma_k}. \qquad (1)$$

If $\delta_i' + a < 1/\gamma_i$ holds for all $i = 1, \ldots, N_c$, then the jitter of the packets for a call in the $i$th CBR class is upper bounded by $\delta_i'$. If, furthermore, $\delta_i' \leq \delta_i$ for all $i = 1, \ldots, N_c$, then all the packets generated by these $\Sigma_{k=1}^{N_c} n_k$ CBR calls meet their jitter constraints.

*Theorem 2*: Define recursively

$$d_j' = \frac{m_j + \sigma_j + 1 + \sum_{k=1}^{j-1} m_k \hat{\sigma}_k + \sum_{k=1}^{N_c} n_k}{\frac{1}{a} - \left(\sum_{k=1}^{N_c} n_k \gamma_k + \sum_{k=1}^{j-1} m_k \rho_k\right)} \qquad (2)$$

for $j = 1, \ldots M_v$, where $\hat{\sigma}_j = \rho_j d_j', + \sigma_j + 1$. If $1/a - (\Sigma_{k=1}^{N_c} n_k \gamma_k + \Sigma_{k=1}^{j-1} m_k \rho_k) > 0$, then the delay of the packets for a call in the $j$th VBR class is upper bounded by $d_j'$, $j = 1, \ldots, M_v$. If, furthermore, $d_j' \leq d_j$, for all $j = 1, \ldots, M_v$, then all the packets generated by these $\Sigma_{k=1}^{M_v} m_k$ VBR calls meet their delay constraints.

The proof of the theorems can be found in [6]. Numerical results of jitter bounds for CBR traffic and delay bounds for VBR traffic are shown in Tables 1 and 2, respectively, where $\delta_i'$ is calculated from Eq. 1, $\delta_i^*$ is from [5], $d_j'$ is calculated from Eq. 2, $d_j^*$ is from [7], and the simulation results are based on the system model above. The VBR traffic is generated in the same way as in [7]. The parameters used to obtain the jitter and delay bounds are listed as follows: the link speed of the wireless channel is 10 Mb/s, all the data packets are 1 kb in length, and the length of a polling message is 50 bits. Time is normalized with respect to the time to transmit a data packet, which is 0.1 ms.

Tables 1 and 2 show that the QoS performance bounds given in Eqs. 1 and 2 are much tighter than those in [5, 7]. The significance of this difference is that a CAC scheme with QoS provisioning by using the improved bounds may result in lower new call blocking and handoff call dropping rates, and admit more calls into the system.

## Call Admission Control with User Mobility Information

Three aspects are included in the proposed CAC scheme:

- Resource reservation for potential handoff calls, updated periodically at each BS
- New CAC, performed whenever a new call request is received by a BS
- Handoff CAC, performed whenever a handoff event occurs

We focus on CAC for CBR and VBR traffic. For ABR traffic, all new and handoff requests are treated the same. There is no resource reservation for ABR handoff calls. All existing ABR calls will share the remaining resources after serving CBR and VBR calls fairly and efficiently through some well-known schemes, such as GRAP in [7].

To admit a call (new or handoff), two conditions must be satisfied. Guaranteed QoS for the particular call should be provided, and QoS performance of all existing calls should still be guaranteed after the admission. Since adding a new call to a BS will impact the QoS performance of all admitted calls with the same and lower priorities, the QoS performance bounds of all the same and lower priority admitted calls should be checked before an admission decision can be made. The same conditions are required to reserve resources for any CBR or VBR class.

User mobility information is used statistically in resource reservation to improve resource utilization. Divide time into equal intervals of length $\tau$ beginning at $t = 0, \tau, 2\tau, \ldots$, so that there is at most one handoff event for any active mobile terminal $x$ in each of the intervals. It is assumed that at the beginning of every $\tau$ interval, the handoff probabilities, $p_{b1b2x}$, of each mobile $x$ from cell $b_1$ to cell $b_2$ are known to the mobile's current cell $b_1$, and all the neighboring BSs can exchange the probabilistic information with each other. Different approaches have been proposed to predict the user mobility information in future moments from its mobility information in current moments [8].

Let cell $o$ (denoted as cell-o) be the reference cell, and define $p_i^c$ and $p_j^v$, respectively, as the number of equivalent handoff calls in the $i$th CBR class and $j$th VBR class, which need cell-o to reserve resources in the next $\tau$ interval. The number of equivalent handoff calls for a traffic class is the average number of calls in the class that will hand off to cell-o in the next $\tau$ interval and can be calculated as the accumulated handoff probability of all the calls in the class that will hand off from the neighboring cells to cell-o in the next $\tau$ interval.

### Resource Reservation for Potential Handoff Calls

The algorithm for resource reservation is shown as pseudocode 1. At the beginning of every $\tau$ interval, resource reservation is updated at each BS for all classes of the traffic from the highest priority (the first CBR class) to the lowest (the last VBR class).

**Pseudocode 1**: Resource reservation

```
/* starts from the first CBR class*/
current_reserved = CBR_1;
/* equivalent number of calls taking the
  potential handoff calls into consideration*/
for i = 1 : TOTAL_NUMBER_of_CLASSES
  equivalent_no(i) = existing_no(i);
end
while(current_reserved != LAST_VBR class)
{
  LAST_flag = 1;
  QoS_guarantee = 1;
  /* treat the handoff equivalent calls as
  existing calls */
  equivalent_no(current_reserved) =
  existing_no(current_reserved)
    + handoff_equivalent_no(current_reserved);
  while(QoS_guarantee & LAST_flag)
  {
  /* QoS bound calculations start from the
  class to be reserved resource */
  current_calculated = current_reserved;
  if (current_calculated is CBR class)
  {
  Calculate jitter bound DELTA(current_cal-
  culated) using the equivalent_no;
  if(DELTA > delta in current_calculated class)
  {
   /* Cannot reserve resource for the
   current_reserved class*/
   QoS_guarantee = 0;
  }
  else
    current_calculated = current_calculated + 1;
    if (current_calculated == LAST VBR)
     LAST_flag = 0;
    end
  end
}
else
{
 Calculate delay bound D(current_calculated)
 using equivalent_no;
 if(D(current_calculated) > d(current_calculated))
 {
  /* Cannot reserve resource for the
  current_reserved class */
  QoS_guarantee = 0;
 }
 else
  current_calculated = current_calculated + 1;
  if (current_calculated == LAST VBR)
    LAST_flag = 0;
   end
  end
 }
 end
}
if (QoS_guarantee != 1)
  /* resource reservation failed*/
  equivalent_no(current_reserved) =
  existing_no(current_reserved);
  end
  current_reserved = current_reserved + 1;
}
```

> *The handoff call dropping rate in the full reservation case is zero. For the partial reservation case, the CAC scheme using the improved new jitter bounds can reduce the forced handoff call dropping rate of both CBR and VBR calls.*

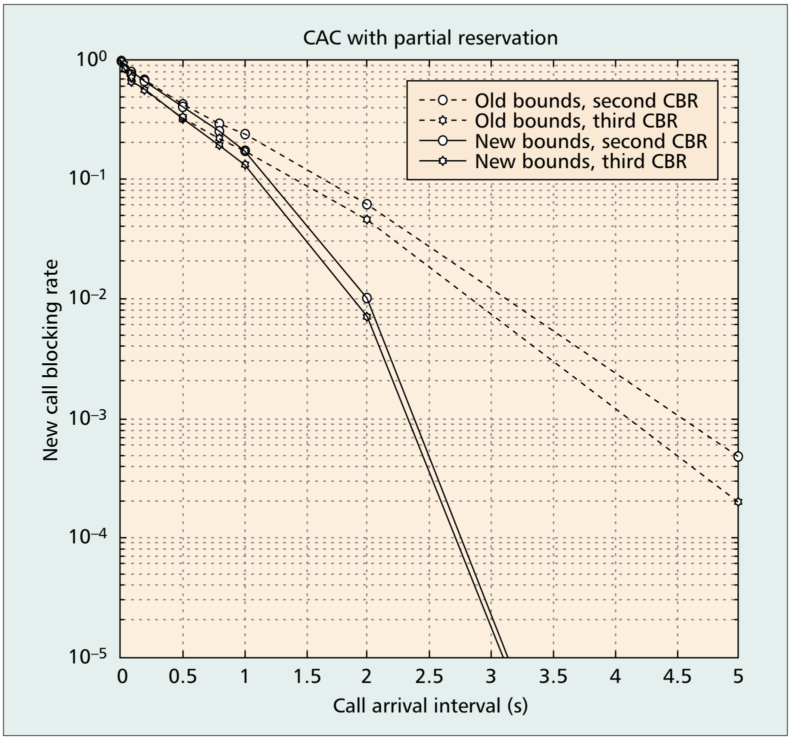


**Figure 2.** *New call blocking rate vs. call arrival interval.*

## Admission Decision for a New/Handoff Call

The algorithm for admission control is shown as pseudocode 2. When a new CBR or VBR call request is received, new CAC is performed. The resources used by all existing calls and those reserved for all potential handoff calls cannot be used by the new call. On the other hand, a handoff call admission decision is made whenever a handoff event occurs. A handoff call can use all the resources unused by the existing calls.

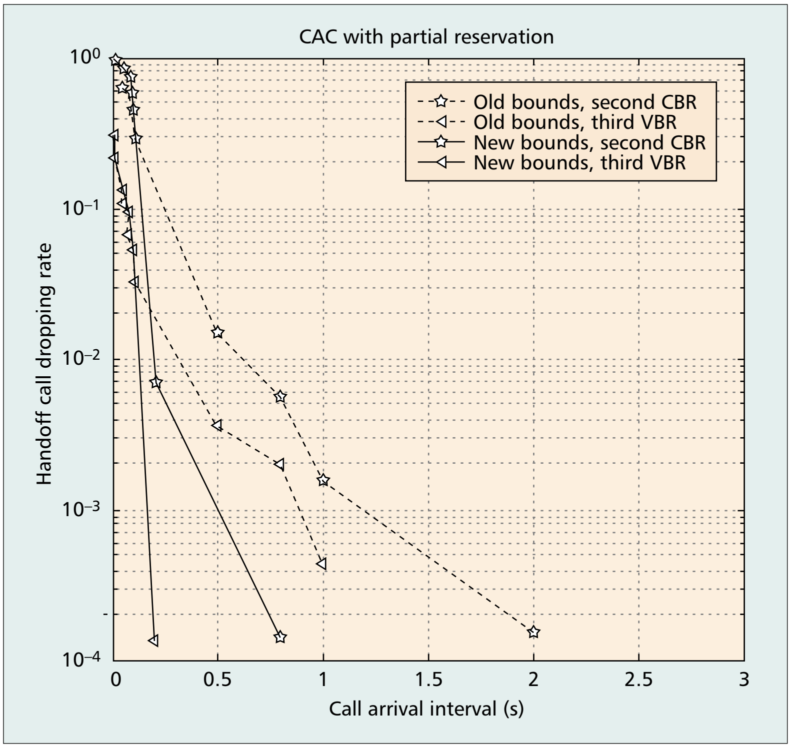


**Figure 3.** *Handoff call dropping rate vs. call arrival interval.*

**Pseudocode 2**: Admission control

```
LAST_flag = 1;
QoS_guarantee = 1;
/* treating the new call as an existing one */
existing_no(its_class) = existing_no(its_class) + 1;
if (the requesting call is a new call)
/* Reserving resources for potential handoff calls */
  for i = 1 : TOTAL_NUMBER_of_CLASSES
   equivalent_no(i) = existing_no(i) + hand-
   off_equivalent_no(i);
  end
end
while(QoS_guarantee & LAST_flag)
{
 /* Bound calculations start from its_class */
 current_calculated = its_class;
 if (its_class is a CBR class)
 {
  Calculate jitter bound DELTA(current_cal-
  culated) using equivalent_no;
  if(DELTA(current_calculated) > delta(cur-
  rent_calculated))
    /* Cannot admit the new call */
    QoS_guarantee = 0;
  else
    current_calculated = current_calculated + 1;
     if (current_calculated == LAST VBR)
      LAST_flag = 0;
     end
  end
 }
 else
 {
 Calculate delay bound D(current_calculated)
 using equivalent_no;
 if(D(current_calculated) > d(current_calculated))
   /* Cannot admit the new call */
   QoS_guarantee = 0;
  else
   current_calculated = current_calculated + 1;
   if (current_calculated == LAST VBR)
    LAST_flag = 0;
   end
   end
  }
  end
}
if (QoS_guarantee != 1)
  /* new call blocking */
  existing_no(its_class) = existing_no(its_class) - 1;
end
```

## Simulation Results

Without loss of generality, consider one-dimensional (1D) cellular arrays. The simulated system has five radio cells arranged in a circle to avoid the boundary effect. Mobile *x* can be in any one of the cells with equal probability. Let the initial location where mobile *x* originates its call request be uniformly distributed in the 1D region of its current cell, where *D* is equal to 1500 m. The mobile can move in either direction of the 1D region with equal probability, and its velocity is uniformly distributed between 5 and 20 m/s. The time interval used to update the resource reservation is $\tau = 60$ s. The handoff probabilities of $x$ from cell-o to its two neighboring cells, cell-r and cell-l, $p_{orx}$ and $p_{olx}$, respectively, are given by

$$p_{orx} = D'/D$$
$$p_{olx} = 1 - D'/D, \tag{3}$$

where $D'$ is the distance between the current location of mobile $x$ and the left edge of its current cell.

The traffic classes in the system are the first three CBR classes in Table 1 and the first three VBR classes in Table 2. Assume that the call arrival process follows a Poisson distribution with parameters $\lambda$, where $1/\lambda$ is varied within the range of (0,10) s, and the call duration is exponentially distributed with the average call duration $1/\mu = 50$ s. For any particular call, it can be any of the six traffic classes (three CBR and three VBR classes) with equal probability.

In the simulation, we compare the new call blocking rate and handoff call dropping rate using our improved bounds from above with that using the bounds in [5], shown as *old bounds* in Figs. 2 and 3. The effects of different resource reservation schemes on new call blocking and handoff call dropping are compared. The schemes include *full reservation* in which 100 percent of resources is reserved for a call in all of its neighboring cells, and *partial reservation* in which a resource is reserved only for potential handoff calls. Figure 2 shows the new call blocking rate for CBR classes in the partial reservation case. It can be seen that the CAC scheme, using the improved jitter bounds for QoS provisioning, can admit more new CBR calls. Similar results can be obtained for the full reservation case. The handoff call dropping rate in the full reservation case is zero. For the partial reservation case, the CAC scheme using the improved new jitter bounds can reduce the forced handoff call dropping rate of both CBR and VBR calls, as shown in Fig. 3. The CAC scheme using user mobility information for resource reservation can achieve a much lower new call blocking rate and higher resource utilization while keeping the handoff call dropping rate at a very low level. Figure 4 shows the case using our developed bound. Similar results can be obtained using the bounds in [5].

In order to evaluate the performance of the proposed CAC scheme, we compare the proposed CAC scheme (scheme 1) with two variants, schemes 2 and 3, which use the improved bounds to do the QoS provisioning and resource reservation in the same way as the proposed CAC scheme. The difference is that when a handoff occurs, a handoff call in the proposed scheme can use all the resources the BS has reserved for the potential handoff calls in all classes; for scheme 2, the handoff call can only use the resources the BS has reserved for the particular class; and for scheme 3, the handoff call can use the resources the BS has reserved for the particular class and all lower-priority classes. Simulation results show that the proposed scheme can achieve a much lower handoff call dropping rate than the other two because of the statistical use of all the reserved resources, while the new call blocking rates are almost the same for all three schemes, because the amount of reserved resources is almost the same for the three schemes.

| CBR classes | Parameters ($\gamma_i$, $\delta_i$) | Bounds in [5] ($\delta_i^*$) | Bounds ($\delta_i'$) | Simulation results |
|---|---|---|---|---|
| 1 | (0.05,12) | 5.25 | 5.25 | 4.20 |
| 2 | (0.01,60) | 30.25 | 14.24 | 9.45 |
| 3 | (0.0075,80) | 50.25 | 22.99 | 10.50 |
| 4 | (0.0064,100) | 65.25 | 32.53 | 15.75 |
| 5 | (0.0032,200) | 130.25 | 42.89 | 21.00 |

**Table 1.** *Jitter bounds of CBR calls when* $n_i = 5$*, where* $i = 1, \ldots, 5$*.*

| VBR classes | Parameters ($\rho_j$, $\sigma_i$, $d_j$) | Bounds in [6] ($d_j^*$) | Bounds ($d_j'$) | Simulation results |
|---|---|---|---|---|
| 1 | (0.00196,7,1200) | 646.52 | 59.98 | 31.50 |
| 2 | (0.00183,6,1200) | 665.36 | 72.79 | 32.55 |
| 3 | (0.00177,6,1200) | 684.23 | 85.69 | 33.60 |
| 4 | (0.00177,6,1200) | 703.25 | 98.77 | 34.65 |
| 5 | (0.00168,5,1200) | 720.25 | 109.71 | 35.70 |

**Table 2.** *Delay bounds of VBR calls when* $m_j = 1$*, where* $j = 1, \ldots, 5$*.*

## CONCLUSIONS

Mobility information is likely to be very useful in CAC for wireless ATM networks, since it can be used to estimate the available and demanded resources in future moments. The accuracy of

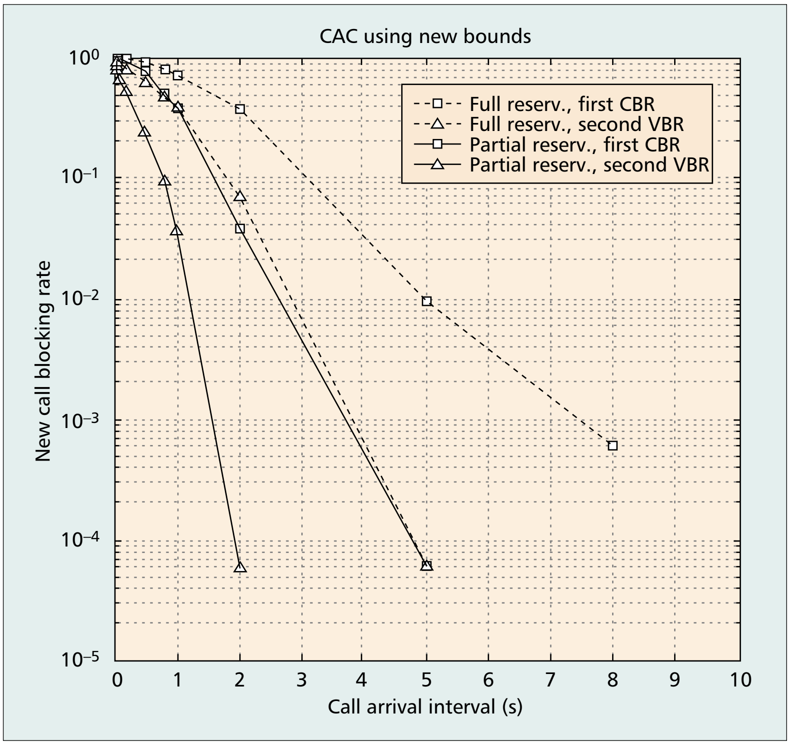


**Figure 4.** *New call blocking rate vs. call arrival interval.*

*The CAC scheme using user mobility information for resource reservation can achieve much lower new call blocking rate and higher resource utilization while keeping the handoff call dropping rate at a very low level.*

resource estimation, which is essential to the CAC scheme, is determined by the available mobility information and the update time ($\tau$). With higher velocity of mobile users and smaller size of radio cells, reduced update time should be used to obtain more accurate mobility information. The deterministic bounds based on the nonpreemptive polling process have been used for QoS provisioning in the proposed CAC scheme. It is anticipated that the performance of the CAC scheme could be further improved with stochastic bounds. Research to find stochastic bounds is underway. Although the nonpreemptive priority polling scheme is more suitable for TDMA systems, the proposed CAC scheme with QoS provisioning is applicable to future 3G wireless networks.

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## BIOGRAPHIES

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