Dynamic Channel Reservation Based on Mobility in Wireless ATM Networks

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ABSTRACT We present a dynamic channel reservation scheme to improve the utilization of wireless network resources while guaranteeing the required QoS of handoff calls. The wireless channels are dynamically reserved by using the request probability determined by the mobility characteristics and channel occupancy to guarantee acceptable quality of handoff calls and keep the new call blocking probability as low as possible.

With the increasing demands for mobile multimedia services, future wireless networks will adopt micro/picocellular architectures in order to provide the higher capacity needed to support broadband services under the limited radio spectrum [1]. Due to its flexible bandwidth allocation, efficient multiplexing of bursty traffic, and provision of a wide range of wireless broadband services, the wireless asynchronous transfer mode (ATM) network is a promising solution for the next-generation wireless communication system. However, handoff will occur frequently in wireless ATM networks because the cell size is much smaller to support higher capacity on the limited radio spectrum. As the handoff rate increases, bandwidth management and traffic control strategy (call admission control, handoff procedure, etc.) become more challenging problems in wireless ATM networks. Handoff is the action of switching a call in progress in order to maintain continuity and the required quality of service (QoS) of the call when a mobile terminal moves from one cell to another [2]. In the wireless environment, we need to consider two additional QoS parameters: dropping probability of handoff calls and blocking probability of new calls from the standpoint of call-level QoS. If the base station (BS) has no idle channels, it may drop the handoff request and cause forced termination of the call in progress. From the subscriber's point of view, forced termination due to handoff calls is less desirable than blocking of a new call. Therefore, the QoS of handoff calls must be guaranteed while allowing high utilization of wireless channels.

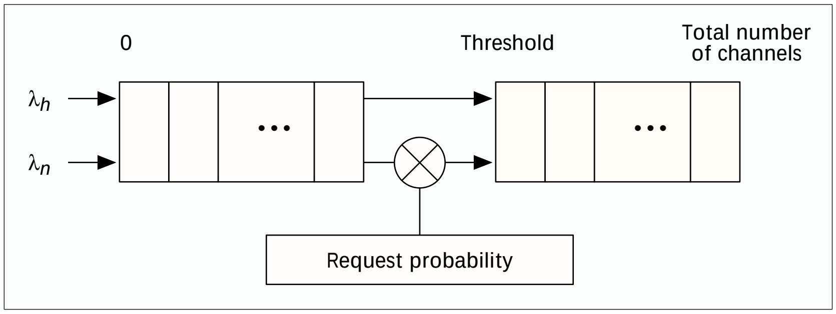
Recently, intensive research on channel allocation schemes has been in progress to reduce the handoff dropping probability. Two generic handoff prioritization schemes are queuing handoff requests and reserving a number of channels exclusively for handoff requests. In general, handoff prioritization schemes result in decreased handoff failures and increased call blocking, which, in turn, reduce total admitted traffic.

One priority scheme is the handoff queuing scheme (HQS). In HQS, queuing of handoff requests is made possible by the existence of the time interval the mobile terminal spends in the handoff area, where it is physically capable of communicating with both the current and next BSs. The fact that successful handoff can take place anywhere during this interval marks a certain amount of tolerance in the delay for the actual channel assignment to the handoff request. New calls which originate within the cell are blocked if all wireless channels are occupied. New calls are served only when a wireless channel is available and no handoff request exists in the queue. Handoff requests are queued in the new BS if no channel is available in the new cell at the time of arrival. As soon as a channel is available in the new cell, it is offered to the handoff request in the queue. HQS reduces the probability of forced termination at the expense of increased call blocking probability and a decrease in the ratio of carried-to-admitted traffic. The reason is that no new call is granted a wireless channel until the handoff requests in the queue are served [3].

Another priority scheme is the guard channel scheme (GCS), which gives higher priority to handoff calls by assigning them a higher capacity limit to reduce the forced termination probability. GCS shares normal channels for handoff and new calls, and reserves exclusively some fixed number of *guard channels* for handoff calls. Because GCS is developed under the assumption of stationary call arrivals, it causes decreased total carried traffic and QoS degradation under nonstationary traffic patterns due to fluctuation of mobility.

With a small portion of handoff calls, GCS may deviate significantly from the requested QoS of handoff calls. Namely, it results in not only increased blocking probability of new calls, but also inefficient utilization of wireless channels, because only a few handoff calls are able to use the reserved channels exclusively. On the other hand, with a large portion of handoff calls, it is difficult to guarantee the QoS of handoff calls. Thus, an efficient channel reservation scheme should take into account the characteristics of traffic mobility in order to use the limited wireless channel efficiently while satisfying the requested QoS of handoff calls.

In this article, we present a dynamic channel reservation scheme (DCRS) based on mobility. The objective of DCRS is to guarantee the required dropping probability of handoff calls while keeping the blocking probability as low as possible. Eventually, the proposed scheme is designed to improve channel utilization while satisfying the QoS of handoff calls. DCRS shares normal channels for new calls and handoff calls, and reserves guard channels for handoff calls. Even though the guard channels are reserved for handoff calls, they can be also used for new calls according to the mobility of calls and status of the network. In order to make new calls use guard channels, the request probability is used to allocate the guard channels to a new call. The request probability of the new call is adaptively determined according to the mobility of calls, total number of channels in a cell, threshold between normal



■ **Figure 1.** *A wireless channel model of the DCRS.*

channels and guard channels, and current number of used channels. A guard channel, if it is available, can be allocated to new calls as much as the request probability.

CHANNEL ASSIGNMENT SCHEMES

QoS provisioning of services and efficient utilization of limited bandwidth are important issues in wireless ATM networks. This article describes the fully shared scheme and GCS. Then we address DCRS and compare the performance of the proposed scheme with that of GCS.

FULLY SHARED SCHEME

The fully shared scheme (FSS) is employed by typical radio technologies that have been proposed for personal communications services (PCS). In FSS, the BS handles the call requests without any discrimination between handoff and new calls. All available channels in the BS are shared by handoff and new calls. Thus, it is able to minimize rejection of call requests and has the advantage of efficient utilization of wireless channels. However, it is difficult to guarantee the required dropping probability of handoff calls, which is less desirable than restricting attempts of new calls for continuity of handoff calls [4].

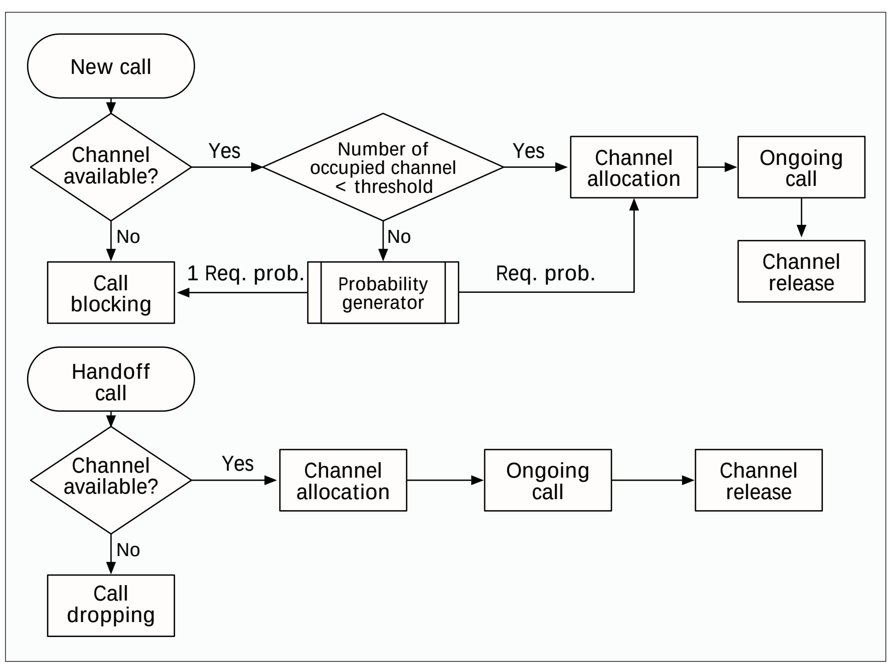
GUARD CHANNEL SCHEME

GCS, which gives higher priority to handoff calls than new calls, is a well-known channel reservation scheme [3–5]. In GCS, a number of wireless channels, called guard channels, are exclusively reserved for handoff calls, and the remaining channels, called *normal channels*, can be shared equally between handoff and new calls. Thus, whenever the channel occupancy exceeds a certain threshold, GCS rejects new calls until it goes below the threshold. Handoff calls are accepted until the channel occupancy goes over the total number of channels in a cell. It offers a generic means to decrease the dropping probability of handoff calls but causes reduction of total carried traffic. The reason total carried traffic is reduced is that fewer channels except the guard channels are granted to new calls. The demerits become more serious when handoff requests are rare. It may bring about inefficient spectrum utilization and increased blocking probability of new calls in the end because only a few handoff calls are able to use the reserved channels exclusively. The use of guard channels requires careful determination of the optimum number of these channels, knowledge of the traffic pattern of the area, and estimation of the channel occupancy time distributions.

THE DYNAMIC CHANNEL RESERVATION SCHEME

The objectives of DCRS are to satisfy a desired dropping of the probability of handoff calls, to reduce the blocking probability of new calls, and to improve the channel utilization. In Fig. 1 λ_h is the arrival rate of handoff calls and λ_n the arrival rate of new calls. The threshold is the boundary between normal and guard channels. In DCRS, both handoff and new calls share equally the normal channels, which are radio channels below the threshold. The guard channels, the remaining channels above the threshold, are reserved preferentially for handoff calls in order to provide their required QoS. Those channels, however, can also be allocated as much as the request probability for new calls instead of immediately blocking, unlike GCS. Thus, handoff calls can use both normal and guard channels with probability one if these channels are available. New calls use normal channels with probability one, but guard channels can be used for new calls according to the request probability. It contributes to reducing the blocking probability of new calls and improving the total carried traffic. Figure 2 shows the call processing flow diagram for DCRS.

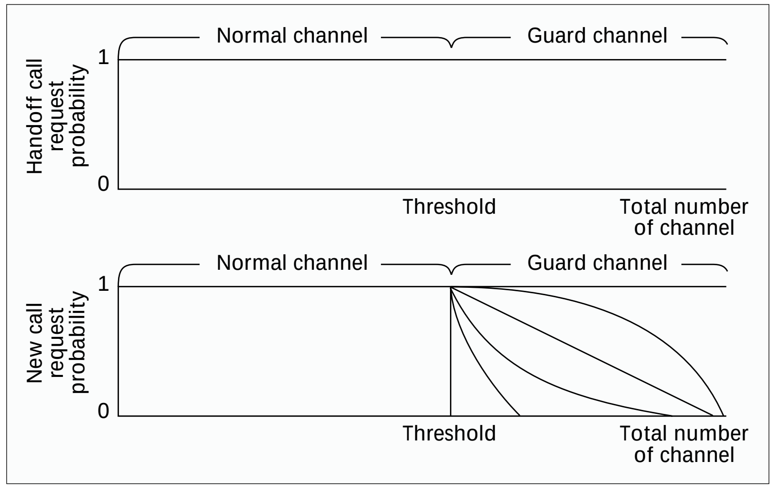
The request probability reflects the possibility that the BS permits new calls to allocate the wireless channel among the guard channels. It is dynamically determined by the probability generator in which the request probability is computed considering the mobility of calls, total number of channels in a cell, threshold between normal channels and guard channel, and current number of used channels. Among these factors, the mobility of calls is most important. The mobility of calls in a cell is defined as the ratio of the handoff call arrival rate to the new call arrival rate.



■ **Figure 2.** *A call processing flow diagram for DCRS.*

REQUEST PROBABILITY

Figure 3 plots the request probability of channel allocation for handoff and new calls. In the normal channels, the request probability for handoff and new calls is one. Therefore, all requests for handoff or new calls are accepted regardless of call type. In the guard channels, the request probability for the handoff call is one. Accordingly, all requests for handoff calls are accepted if available channels exist. However, new calls can access the guard channels with the request probability. The request probability is classified into three categories. As an extreme case, the first operates like GCS if the distribution of the traffic consists of handoff calls only. On the other hand, the second one operates like FSS in the extreme if the handoff traffic is zero. The request probability of the third is dynamically determined according to traffic pattern due to mobility of calls.



■ **Figure 3.** *Request probability for the channel allocation.*

When the arrival rate of handoff calls is larger than that of new calls (the mobility of calls is larger than one), the request probability should quickly be reduced to give more opportunity for accessing guard channels to handoff calls (decreasing with concavity). When most of the requested calls trying to acquire the radio channels are handoff calls, the request probability must be determined close to zero. In this case, DCRS will gradually get close to GCS according to increased mobility of calls. Consequently, more wireless channels can be allocated to handoff calls in proportion to increased mobility of calls, and the dropping probability of handoff calls can be guaranteed.

On the other hand, when the arrival rate of handoff calls is lower than that of new calls (the mobility of calls is smaller than one), the request probability for new calls should slowly be reduced in the guard channels to give more opportunity to new calls (decreasing with convexity). The request probability must be determined close to one since most of the requested calls are new calls. In this case, DCRS will get close to FSS according to decreased mobility of calls. Consequently, more wireless channels can be allocated to new calls, and it has the advantages of reduced new call blocking probability and increased channel utilization.

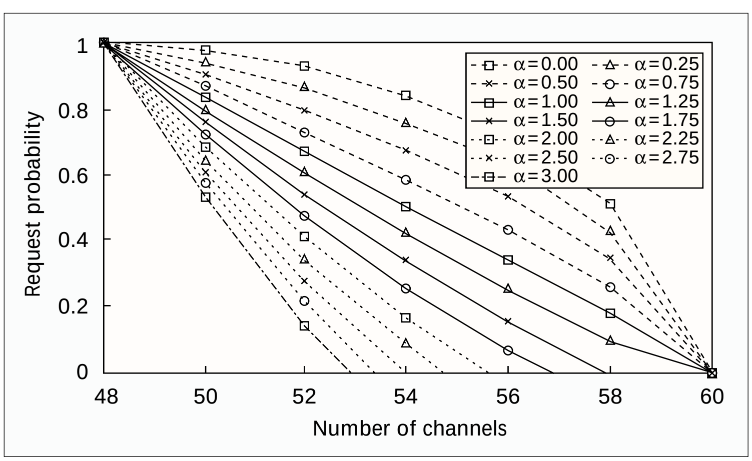
When the mobility of calls equals one, request probability for new calls decreases linearly. Therefore, half of the guard channels can be allocated to new calls.

We defined a heuristic formula of the request probability for the new calls considering the mentioned concepts as follows [6]:

$$\mathrm{MAX}\left\{0, \alpha\left[\frac{C-i}{C-T}\right] + (1-\alpha)\left[\cos\frac{2\pi(i-T)}{4(C-T)}\right]^{1/2}\right\}$$

A CASE STUDY OF REQUEST PROBABILITY

Figure 4 shows an example of the request probability determined by the proposed heuristic formula under the total number of channels of 60, threshold of 48, and various degrees of call mobility. The request probability increases relative to decreasing call mobility and decreases relative to increasing call mobility under the same network situation. When the mobility of calls equals one, the request probability is reduced linearly in proportion to the increase in the number of busy channels in a cell. When the mobility of calls is smaller than one, the request probability is smoothly decreased in order to provide more opportunity to new calls. When the mobility of calls is larger than one, the request probability is abruptly decreased in order to provide more service opportunity to handoff calls. If the mobility of calls is much larger than one, the request probability will be determined to zero. From this figure we can understand that DCRS dynamically operates depending on the varying situation of network traffic.

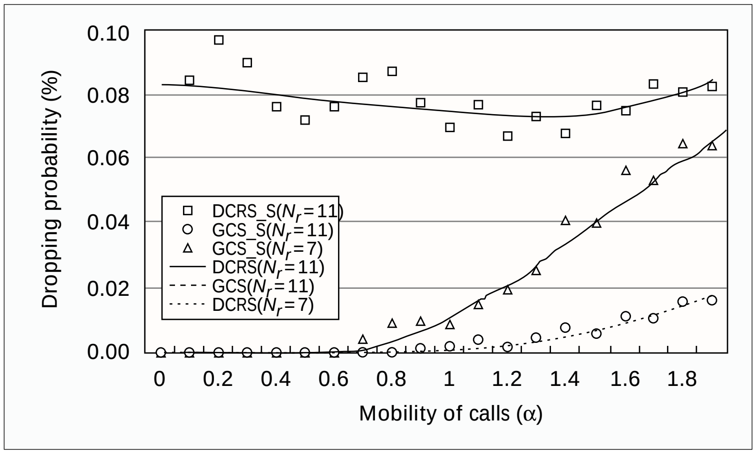


■ **Figure 4.** *Request probability for new call (*C = *60,* T = *48,* α *is the mobility of calls).*

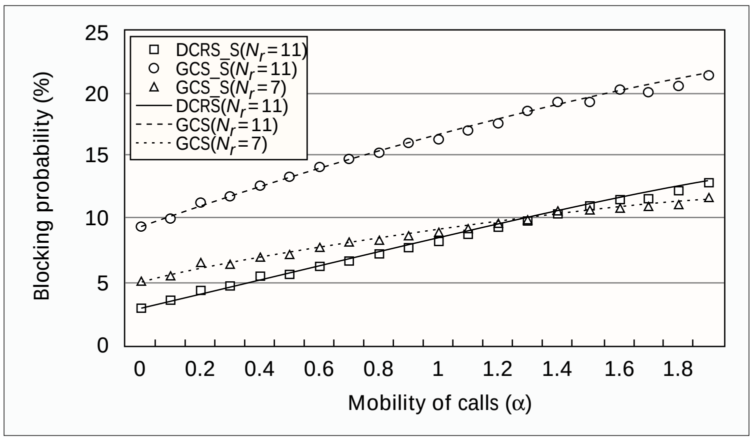
A PERFORMANCE EVALUATION OF DCRS

The author of DCRS presented an analytical and simulation model to evaluate its performance in [6]. This section summarizes the results in [6], which assumed that the number of mobile users is much larger than the total number of channels in the BS so that call arrivals may approximate to a Poisson process. Such an assumption was also used in [3, 5, 7]. It also assumed that there is a single service class with the same fixed capacity for simplicity. Following are the traffic parameters and performance metrics used to evaluate the performance of DCRS:

- C: the maximum number of available channels in the BS.
- N_r: the number of reserved channels.
- ρ: offered load. The offered load is a measure of the demand made on the BS and is defined as the ratio of total call arrival rate to call completion rate.
- α: the mobility of calls. The mobility of calls is a measure of terminal mobility and is defined as the ratio of handoff call arrival rate to new call arrival rate.
- P_B: blocking probability. The reserved channels



■ **Figure 5.** *A comparison of dropping probability of DCRS and GCS (*C *= 60,* ρ *= 0.8).*



■ **Figure 6.** *A comparison of blocking probability of DCRS and GCS (*C *= 60,* ρ *= 0.8).*

above the threshold can be allocated to new calls as much as the request probability. Therefore, the new call blocking probability is defined as the sum of steady state probability that requests for new calls are not accepted between the threshold and C.

- P_F: dropping (forced termination) probability. If idle channels exist, they can always be allocated for requests of handoff calls. The dropping probability of handoff calls is defined as the probability that all channels are busy. We set the target dropping probability as 0.1 percent.

Figures 5, 6, and 7 compare DCRS with GCS in terms of dropping probability, blocking probability, and channel utilization for varying call mobility.

Dropping Probability

Figure 5 shows the dropping probability as functions of mobility for C = 60 and ρ = 0.8. Note the good agreement between the performance analysis and the simulation. As shown in Fig. 5, we can observe that both DCRS and GCS satisfy the target dropping probability (0.1 percent). The dropping probability of GCS is very sensitive to call mobility and deviates significantly from the targeted objective according to decreasing the mobility of calls in a cell. In the case of high call mobility, this implies that the more handoff calls arrive, the more handoff calls could be forcibly terminated. GCS cannot guarantee the targeted QoS above α = 1.8. On the other hand, GCS oversatisfies the targeted objective when call mobility is low. This implies that channels are used inefficiently. However, DCRS preserves the dropping probability at a nearly constant level regardless of the variant of mobility, implying that DCRS can efficiently use the wireless channels while satisfying the QoS of handoff calls.

Blocking Probability

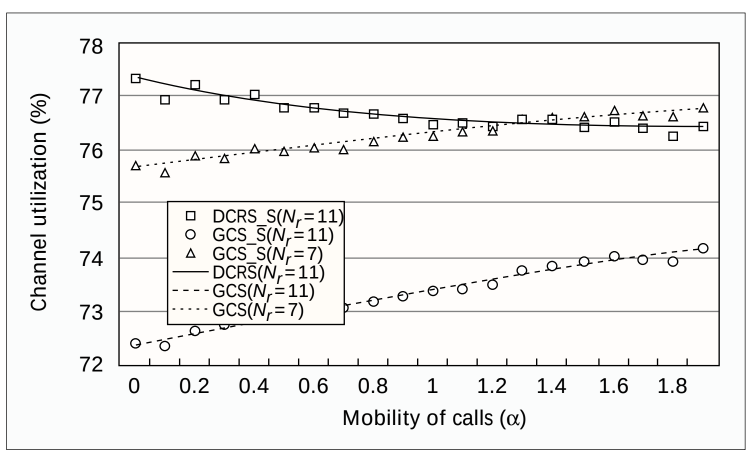
In Fig. 6, the more the mobility of calls increases, the more blocking probability takes place. This means that the chance of new calls allocating the wireless channels successfully is diminished because a request for handoff preempts the wireless channel. It shows that for N_r = 11, DCRS is superior to GCS in the performance of blocking probability. The average blocking probability is 13.2 percent in GCS and 5.9 percent in DCRS. GCS with a small number of reserved channels (N_r = 7) is similar to DCRS with N_r = 11, but the blocking performance of DCRS is still better than GCS. The average of blocking probability is 7.4 percent in GCS. Consequently, DCRS effectively reduces the blocking probability under the same threshold. This property is related directly to the throughput and is important in wireless networks since the radio spectrum has inherent bandwidth limitations.

Channel Utilization

Figure 7 shows that the channel utilization of DCRS is higher than that of GCS for same threshold (N_r = 11) and similar to that of GCS with a small number of reserved channels (N_r = 7). The average channel utilization in GCS is 72.9 percent and 76 percent where N_r = 11 and N_r= 7, respectively. In DCRS, average channel utilization is 76.9 percent. Especially, the channel utilization of DCRS is getting better than that of GCS when increasing the offered load [6].

Conclusions

In this article we proposed DCRS to improve wireless channel utilization. Normal channels are shared by both new and handoff calls. Even though guard channels are reserved for handoff calls, they can be allocated to new calls according to the request probability in order to increase channel utiliza-



■ **Figure 7.** *Channel utilization (*C *= 60,* ρ *= 0.8).*

tion. The dynamic channel reservation scheme has three main features, as follows:

- The dynamic channel reservation scheme operates like the fixed guard channel scheme if most of the requested calls are handoff calls.
- The dynamic channel reservation scheme operates like the fully shared scheme if most of the requested calls are new calls.
- The dynamic channel reservation scheme operates dynamically according to the mobility of calls.

We have determined a heuristic formula for the request probability which takes into account the total number of channels in a cell, the threshold, the mobility characteristics, and information related to channel occupancy.

Both DCRS and GCS satisfy the target forced termination probability, but DCRS preserves the dropping probability at a nearly constant level regardless of the mobility variant. This property provides much room for improving blocking performance and channel utilization. DCRS reduces the blocking probability effectively, which, in turn, improves the total carried traffic. Consequently, DCRS takes advantage of higher channel utilization than GCS. This feature is important in wireless networks since the radio spectrum has inherent bandwidth limitations.

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