New Handoff Strategies in Microcell/Macrocell Overlaying Systems

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Abstract. To cope with the increasing demand of mobile and personal communications, two-tier cellular systems are likely to be deployed in major city center. Reservation schemes are consequently to be adapted to such a context: forced call terminations due to handoff call blocking are generally more objectionable than new call blocking. In order to maintain an acceptable call dropping probability rate, we propose, below, a new adaptive guard channel scheme : Hierarchical Predictive Reservation Policy (HPRP). In this scheme, the number of reserved channels depends on the actual number of calls in progress in the neighboring cells. In micro/macrocels systems, users are assigned to a given level of the hierarchy according to their speed. In this paper, three schemes are proposed and compared by discrete event simulations. The efficiency of the proposed methods is emphasized on a complex configuration.

1 Introduction

Personal Communication Networks (PCN) have emerged as an important field of activity in telecommunications [9]. Among all the encountered problems, the implementation of broadband features on the wireless medium is one of the most difficult to handle: a large bandwidth is required to offer such services with a quality of service similar to those of wired networks. Future PCNs will employ micro-cells and pico-cells to support a higher capacity, and thus increasing the frequency of handoff calls and dramatizing the effects of non-uniform traffic conditions due to mobility patterns in the covered regions (roads, dead-ends, ...). Hierarchical microcell/macrocell architectures have been proposed for future personal communication systems. These architectures provide capacity relief to a macrocell system and offer many advantages over a pure microcell system [11]. Furthermore, the fast handoff requirement in a pure microcell system can be relieved in the overlaying architecture by temporarily connecting the call to a macrocell Base Station (BS). In a two-tier system (of microcells overlaid with umbrella macrocells), low mobility users (e.g. pedestrians) should be assigned to microcells and undergo handoffs when crossing microcell boundaries, while high mobility users (e.g. cars) should be assigned to macrocells and undergo handoffs when crossing macrocells boundaries. In this paper, different admission strategies are considered.

To support network-wide handoffs, new and handoff calls will compete for requesting resources. Handoff calls require a higher congestion-related performance, i.e. blocking probability, with regard to new calls in order to minimize subscriber dissatisfaction. Different methods for accessing resources were proposed [14] [1]. In mobile networks, one common bandwidth resource access priority scheme is the guard channel scheme [5] [3] [4] [12]. In this paper, we propose a new dynamic guard channel scheme: Hierarchical Predictive Reservation Policy (HPRP). In this scheme, the number of guarded channels depends on the actual traffic parameters in order to achieve the Quality of Service requirements for both new call blocking and handoff blocking probabilities. A multi-period traffic representation has been considered. The values of the HPRP parameters have to be optimized for each time period. In HPRP, the number of reserved channels depends on the number of ongoing calls in neighboring cells (i.e. micro/macro cells) and on the routing probabilities of mobiles.

Discrete event simulations of these schemes were run. We demonstrate the effectiveness of our reservation method thanks to a complex and realistic multi-cell configuration, and we present performance evaluation under different traffic loads.

This paper is organized as follows. Section 2 describes the adaptive guard schemes. In section 3, the simulation model is presented and the performance results of the proposed guard algorithm and of the different admission strategies are analyzed. We conclude the paper in section 4.

2 Models for adaptive guard bandwidth schemes and admission strategies

2.1 Introduction

The fixed guard bandwidth scheme is a prioritized resource access scheme which allows new calls and handoff calls to share the capacity, by giving a resource access priority to handoff calls. Since a larger resource capacity limit is given to handoff calls, the guard channel is defined as the difference between the two capacity limits. In this paper, we only consider congestion control based on the blocked-calls-dropped discipline. The resource access priority for handoff calls may be further increased by employing the blocked-calls-queued discipline [12]. The problem discussed in this paper is the following: since the traffic patterns are not uniform, how many channels may be reserved to handoff calls in the different cells?

We define $\Phi(i)$ as the set of the microcell i neighbours. p_{ij}^l (resp. p_{ij}^h) denotes the probability for a given low speed mobile (resp. high speed mobile) to move from a microcell number i to a neighbouring microcell number j . In the different examples, only the case $p_{ij}^l = p_{ij}^h$ has been considered. In fact, those probabilities might be estimated as a function of the speed of the user. The reservation policies may also depend on those parameters. It should lead to more complex policies ; the optimization of the different thresholds would be much more

complicated. Furthermore, in this paper, only micro/microcell transition probabilities are considered; other reservation schemes may have been designed. Our purpose was mainly to show the influence of reservation schemes based on traffic parameters on the performance of hierarchical cellular networks.

2.2 The HPRP Algorithm

In a microcell i , calls may be connected to the microcell Base Station ($\mu_BS(i)$) or the corresponding macrocell Base Station ($M_BS(i)$). C_i^μ and C_i^M are the number of channels in $\mu_BS(i)$ and in $M_BS(i)$. Let $N_i^\mu(t)$ and $N_i^M(t)$ denote the number of users in microcell i connected at time t respectively to $\mu_BS(i)$ and to $M_BS(i)$. When the number of occupied channels $N_i(t) = N_i^\mu(t) + N_i^M(t)$ in a given microcell reaches a threshold k or a multiple of k (see Fig. 1), resources are reserved in the neighbours for which the probability of transition is high. We suppose that the number of mobiles in a given micro-cell is managed by a controller of a cluster of cells. k is a HPRP parameter, it has to be optimized in order to improve the performance of the system. In fact, reservations are made in the corresponding macrocell. No reservation scheme has been considered at the microcell level. This is due to the fact that in the different schemes, the users that may not be accepted at the microcell level may be connected to the corresponding macrocell and that microcell channels are mostly occupied by pedestrian users for which handoff rate is quite low. If $M_BS(i)$ has free channels, the reservation takes place immediately. Otherwise, the HPRP algorithm waits for a free channel. A reserved channel corresponds to the potential arrival of a communication. Two intervals are considered: if the transition probability is lower than a given value p , no reservation are made, else the reservation threshold is k . The blocked channels can only be used for handoffs. In case of overload (or a state close to the overload), the system does not accept incoming calls but only processes calls in progress.

Fig. 1. Principle of HPRP reservation

Ex: $k = 10$ and $p = 0$

$N_i(t) = 10 \rightarrow 1^{st}$ reservation (or request for a reservation) in the neighbours of i .

$N_i(t) = 20 \rightarrow 2^{nd}$ reservation (or request for a reservation) in the neighbours of i .

Reservations are cancelled when the number of occupied channels becomes lower

than a threshold. When $N_i(t)$ goes down from 20 to 19 the 2nd reservation (or request for a reservation) is cancelled.

2.3 Call and Handoff Admission Strategies

Once the frequencies are allocated on micro and macro layers, terminals may be served by the two layers. The question that rises is to know which policy provides the best efficiency. Many strategies were proposed in the literature [13] [10] [6] [2] [7]. Two mobility behaviours are usually considered : pedestrians are quasi-fixed while cars move quickly. In order to maximize the system efficiency, low-speed users are mostly connected to the lower layer while upper layer is used by high-speed users and act as overflow for low layer. In non-reversible systems, a call is never taken back by the lower layer. In reversible systems, the call may be taken back by the microcell layer when a resource is available. In the present paper, three solutions were studied.

First Scheme (P1). In the first scheme, when a mobile gets into a new microcell areas, the system tries to connect it to the microcell level. When there is no resource left in the microcell base station, it can be temporarily connected to the macrocell level if there is a free channel (cf. Figure 2).

Fig. 2. Admission Policy - First Scheme (P1)

Second Scheme (P2). In the second scheme, the previous algorithm is applied to low-speed users. High-speed users try first to access the microcell layer and then overflows to the macrocell if there is no available channel. Once there are connected to the macrocell level they will only experience macro/macro cell handoff and can only be connected to macrocell base stations (see Figure 3.).

Third Scheme (P3). The second scheme algorithm is applied to high-speed users. In order to minimize the number of handoffs for low-speed users, when a pedestrian has to be connected to a macrocell base station, it will stay at this level whenever it stays in the same macrocell area. When it enters a new macrocell, it will again access the low-layer level, if there is enough resource (cf. Figure 4.).

Fig. 3. Admission Policy - Second Scheme (P2)

Fig. 4. Admission Policy - Third Scheme (P3)

3 Simulation model and results

3.1 Simulation Model and Performance Criteria

We simulated the operations of the proposed dynamic guard bandwidth scheme in a mobile wireless system with radio cells having different traffic characteristics. A 36-cell configuration has been chosen. In the first example -General Case- different new call arrival rates and non-uniform transition probabilities are considered. In the second one -Realistic Case- roads, cross-roads, dead-ends, ... are simulated. The routing probabilities are chosen as a function of the topology (cf. Figure 5). For instance, $p_{7,8}$ and $p_{7,12}$ are high (main street), $p_{7,1}$ is nearly zero (one-way street), and new call arrival rates are particularly high in a residential area (cell 13).

Discrete event simulations were run in order to estimate the performance criteria (new call and handoff blocking probabilities and the Grade of Service).

In this paper, classical assumptions are made. We assume that for each time period the traffic is characterized by the arrival of new calls in each microcell and by the transition probabilities of micro/micro handoff calls. The arrival process of new calls is assumed to be Poisson for both low speed (index l) and high speed users (index h) with respective rates λ_i^l and λ_i^h which depend on the microcell i . The call duration and the sojourn time of a mobile within a given cell are supposed to have a negative exponential distribution with the parameters μ_c^h and

Fig. 5. Description of the simulation model

μ_s^h for the high speed users and μ_c^l and μ_s^l for the low speed users. In this paper, we shall assume that $\mu_c^l = \mu_c^h$.

A useful performance criteria is the Grade of Service (GoS) which can be defined as follows for class k traffic :

$$GoS^k = P_{nc}^k + \alpha P_{ho}^k. \quad (1)$$

where P_{nc}^k and P_{ho}^k denote respectively the new call and the handoff blocking probabilities for class k users. In order to comply with the QoS constraints of the cellular networks, α is set to 10 (e.g. P_{nc}^k should be lower than 10^{-2} and P_{ho}^k lower than 10^{-3}).

3.2 Results

Fig. 6. Grade of Service as a function of the traffic load (expressed in Erlang) - First Scheme - General Case

Fig. 7. Grade of Service as a function of the traffic load (expressed in Erlang) - Second Scheme - General Case

Results - General Case. Let us first present the simulation results in the General Case. In Figures 6, 7 and 8, we represented the GoS as a function of the traffic load (expressed in Erlang).

Fig. 8. Grade of Service as a function of the traffic load (expressed in Erlang) - Third Scheme - General Case

The number of channels in the microcell level is $C_i^\mu = 4$ and the number of channels in the macrocell level is $C_i^M = 80$. The best performance results were obtained with $k = 12$ and $p = 0.35$.

In this general scheme, we wanted to show the influence of the reservation mechanism. In fact, since the number of channels in the lowest level is equal to 4, the different assignment algorithms nearly lead to the same performance results (same order of magnitude). In the three schemes, HPRP really improves the performance of the system. The improvement increases with the traffic rate; for a load of 11.5 Erlangs, it is between 20 % and 40 %. Consequently, it is shown that the reservation principles described below are efficient and may be applied to a more realistic traffic case [1].

Results - Realistic Case. In Figures 9, 10 and 11, we represented the GoS as a function of the traffic load (expressed in Erlang). In order to compare the different assignment schemes, the number of channels in the microcell level is $C_i^\mu = 8$ and the number of channels in the macrocell level is $C_i^M = 64$.

Fig. 9. Grade of Service as a function of the traffic load (expressed in Erlang) - First Scheme - Realistic Case

In the first scheme, since the assignment algorithms are the same for both pedestrians and cars, performance results are nearly the same.

Fig. 10. Grade of Service as a function of the traffic load (expressed in Erlang) - Second Scheme - Realistic Case

In the second scheme, the number of handoffs of the cars decreases. But, since cars are mostly connected to the macrocell level, they may be blocked even if there is free channels in the microcell level. Consequently, this scheme leads to an underutilization of the bandwidth. In this scheme, pedestrians try to stay at the lowest level as long as possible. So, they may free a macrocell level channel when they get into a new microcell and then they may be blocked during the next handoff even in the same macrocell. It finally leads to a great difference

between the GoS for the two kinds of traffic.

Fig. 11. Grade of Service as a function of the traffic load (expressed in Erlang) - Third Scheme - Realistic Case

In the last case, the bandwidth utilization is worse than in the previous case because pedestrians stay longer at the highest level. The GoS is nearly the same for both low-speed and high-speed users.

The first scheme leads to the best performance results but introduces many handoffs, especially for high-speed users. The last two policies reduce the number of handoffs but the channels of the microcell layer are underloaded and consequently lead to bad performance results. The last policy is easy to implement in a realistic system but the number of microcell channels has to be low. The best performance results of HPRP are obtained with the same threshold values. In this case, HPRP strongly improves the GoS in the different assignment algorithms. For a GoS near 0.01, the improvement is about 30% in the three cases. It is shown that the relative improvement depends on the admission policy and on the local topology. But, in all the different cases, the use of HPRP reveals itself efficient.

4 Conclusion

In this paper, a new guard channel algorithm has been proposed: HPRP. The required guard bandwidth can be calculated off line and loaded into lookup tables to facilitate the dynamic allocation. This mechanism has been implemented in a hierarchical architecture of micro/macrocels. Three call and handoff strategies were proposed for both low-speed and high-speed users. Two configurations were simulated : in the first one -general case- non-uniform traffic conditions were considered, in the second one -realistic case- a given topology of roads, dead-ends ... has been chosen. In all the considered examples, HPRP leads to an improvement of nearly 30% of the grade of service.

It is shown that if some cell to cell handoff probabilities are known (even approximately), it is possible to use them in order to manage the bandwidth efficiently.

Adaptive reservation schemes prove to be efficient, especially when the traffic is unbalanced, which seems to be a realistic assumption.

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