Bounds and Performance of Reuse Partitioning in Cellular Networks*

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Abstract

In this paper we study a scheme that allows a smooth increase of the capacity of a cellular system for circuit-switching by applying cell-partitioning and using dynamic channel allocation techniques. A bound is computed for this reuse partitioning scheme that gives the maximum theoretical gain accomplished in the system bandwidth. The performance of the proposed scheme, in terms of blocking probability, is evaluated both when the position of the mobiles remains unchanged and when mobility is taken into account. The numerical results show that the capacity of the proposed scheme is sensibly higher than that of a fixed allocation scheme.

1 Introduction

The demand for mobile telephone services is expected to grow rapidly. Increasing the capacity of modern cellular systems, i.e. the number of subscribers per unit of area handled at some minimum quality of service, is one of the main issues for the research about this systems. In this direction the key role is played by the limited radio spectrum available.

To increase the capacity of the system three different approaches can be followed: reducing the cell size, lowering the ratio between the carrier reuse distance and the cell radius (D/R), and optimizing the frequency allocation policy. The first method has the drawback of requiring the increase of the number of base stations proportionally to the requested growth of capacity. On the other hand, minimizing the D/R ratio, as well as reducing the single user channel bandwidth, affects the robustness to interference of the modulation and coding techniques.

With regards to the allocation policy we can effectively classify them [1] into three categories: fixed strategies, dynamic strategies and flexible strategies. The common concept in all fixed assignment strategies or FCA (fixed channel allocation) is the permanent allocation of a set of radio carriers to each cell. Because radio signal strength attenuates with distance, the same set of frequencies can be reused by another cell (*co-channel cell*) some distance away. The minimum distance between two co-channel cells, which allows the respective mobile users to communicate without unacceptable co-channel interference regardless of their position within the cell, is called the co-channel reuse distance (D). This quantity depends both on the minimum SIR (Signal-Interference Ratio) allowed, which determines the D/R ratio, and on the cell radius (R). In the basic FCA a call attempt in a cell can only be served if there is an idle channel among those available on the carriers preassigned to the cell.

In this paper we describe a reuse partitioning algorithm where the entire set of radio carriers has been partitioned into two or more subsets. A different reuse distance is associated with frequencies belonging to each of the subsets. We show here that reuse partitioning achieves an asymptotic doubling of the system capacity.

In the technical literature some works [2] [3] [4] [5] study borrowing techniques that can be considered variations of the basic fixed assignment scheme. Fixed assignment schemes have been shown to be effective in systems with high and constant loads. However, they fail to provide high capacity in presence of non-stationary traffic conditions due to users mobility.

The key idea of the dynamic strategies, or DCA (dynamic channel allocation), is to perform a real-time radio resource allocation based on the actual cells conditions, instead of relying on a priori information. Several implementations of this concept have been proposed and studied in previous works [6] [7] [8] [9]. In this paper we describe a DCA algorithm suitable to be applied in a cellular network based on our reuse partitioning concept. A related work [13] has recently

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been published which provides some bounds on the use of DCA techniques in cellular networks with reuse partitioning. We consider calls generated by a finite number of users moving in a limited service area. Additionally, user mobility is also investigated.

As for the paper organization, in section 2 we present the reuse partitioning algorithm and compute the corresponding bandwidth increase factor. Traffic and mobility models are described in section 3, whereas the proposed DCA algorithm is presented in section 4. Performance results of this latter scheme are finally given in section 5.

2 The reuse partitioning algorithm

2.1 Basic algorithm

A communication service is to be provided in a given geographical area by using a set of Q carriers. The principle of a cellular environment is to divide the area into cells, whose shape is usually assumed to be hexagonal, so as to model the simplest network environment. We assume that a base station is available in each cell, located in the center of the cell whose radius is R. The basic principle of a cellular network is that each carrier can be used at the same time in several cells (co-channel cells), given that the minimum distance between them is D.

Cells are divided into clusters of M adjacent cells, so that the whole area has been partitioned into non-overlapping clusters. Each carrier can be used by only one cell of the cluster at any time. The cells in all clusters are labeled in the same way so that the distance between cells with the same label in adjacent clusters is the same and coincide with the reuse distance D. Therefore two co-channel cells cannot belong to the same cluster. The simplest technique for allocating carriers to cells is the *Fixed Channel Assignment* (FCA): the Q carriers are divided into groups of $q = Q/M$ carriers, each assigned permanently to cells with the same label. Therefore the frequency reuse technique, typical of cellular environments, enables to increase the available capacity of Q carriers by a factor equal to the number of clusters.

Given the hexagonal cell shape, it immediately follows from topological considerations that the admissible values of D are defined once we choose the cluster size M

$$D = \sqrt{3M} \cdot R. \tag{1}$$

Once a given SIR has been selected according to transmission power budget criteria, the ratio $\sigma = D/R$ between the minimum reuse distance and the cell radius is set. After the cell radius has been chosen based on user traffic considerations, the parameter D is automatically assigned. Typically a minimum allowed SIR of 18dB is assumed. Therefore, supposing a radio signal power attenuation with the fourth power of distance, the D/R ratio must be at least 4.58 [10]. From Eq. 1 it follows that the cluster must include at least $M = 7$ cells.

Given a total number of cells in a cellular network, which also equals the total number of base stations, our objective is to increase the total network transmission capacity without increasing the number of carriers. According to Ref. [12] this goal is achieved by enabling a smaller reuse distance of a subset F_s of the entire carriers set F available in the network.

Let D_l and R_l denote now the previous symbols D and R, and assume that a carrier, say $f_s \in F_s$, is used with a reuse distance $D_s < D_l$. Since the total number and position of the base stations must not be changed, D_s can assume only a few values compatible with the given array of base stations. Owing to the smaller reuse distance of the carriers in the set F_s, the coverage radius R_s of these carriers must be such that

$$\frac{D_s}{R_s} = \frac{D_l}{R_l} = \sigma \tag{2}$$

Apparently, $R_s < R_l$. This smaller (hexagonal) area will be denoted as *core*, whereas the term *ring* identifies the region in the cell outside the core. Fig.1 shows

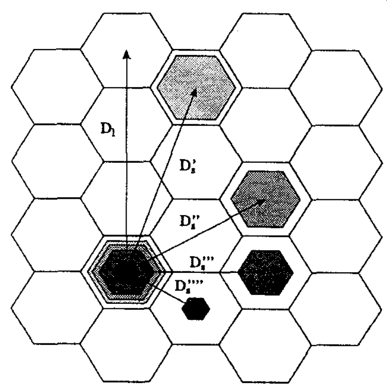

Figure 1: Cell reuse partitioning.

all the possible choices for D_s given D_l. Once D_l and D_s have been selected, two different cell clusters are identified which include M_l and M_s cells respectively. If ξ denotes the ratio R_s/R_l, it can be shown that ξ also relates the two cluster sizes. In fact, by expressing the reuse distance D_s as a function of the basic cell radius R_l by means of $D_s = \sqrt{3M_s} \cdot R_l$ (see Eq. 1), it follows from Eqs. (2) and (1) that

$$\frac{R_l}{R_s}\sqrt{3M_s} = \sqrt{3M_l} \tag{3}$$

and hence

$$\xi = \frac{R_s}{R_l} = \sqrt{\frac{M_s}{M_l}} \tag{4}$$

Let F be the set of carriers available in the network ($|F| = Q$). The set F will be suitably partitioned in two subsets F_l and F_s, with cardinality Q_l and Q_s, to be used with respective reuse distance D_l and D_s. The carriers in F_l and F_s are referred to as *long haul frequencies* (*lhf's*) and *short haul frequencies* (*shf's*). Hence each cell has available $q_l = Q_l/M_l$ lhf's and $q_s = Q_s/M_s$ shf's, summing up to a total number of carriers in the cell $q = q_l + q_s$.

In order to understand how this reuse partitioning technique affects the network traffic performance we introduce two simplifying assumptions:

- q_l (q_s) is proportional to the number of users in the ring (core);
- the user density is uniform throughout the network.

Due to these assumptions we have:

$$\frac{q_s}{q} = \frac{R_s^2}{R_l^2} = \xi^2 \tag{5}$$

$$\frac{q_l}{q} = \frac{R_l^2 - R_s^2}{R_l^2} = 1 - \xi^2 \tag{6}$$

Then the total number of carriers Q is computed by

$$Q = Q_s + Q_l = q_s M_s + (q - q_s)M_l =$$
$$= M_l q \left(\frac{M_s}{M_l}\frac{q_s}{q} + 1 - \frac{q_s}{q}\right) = M_l q(\xi^4 + 1 - \xi^2). \tag{7}$$

The number q' of carriers per cell in a classical cellular environment without our partitioning scheme is $q' = Q/M_l$. Therefore the maximum increase in the network capacity provided by the reuse partitioning scheme is accomplished when the function $B(\xi) = q'/q$ has minimum value. By means of Eq. 7 we obtain

$$B(\xi) = \xi^4 + 1 - \xi^2 \tag{8}$$

By taking the first derivative of $B(\xi)$ and setting it to zero, we find that the minimum is obtained when $\xi = \sqrt{1/2}$. Therefore the capacity increase factor in the network is given by $B^{-1}(\sqrt{1/2}) = 1.33$ (33% additional bandwidth is available). Owing to the physical meaning of ξ, the optimum cell partition occurs when the core and ring areas are equal to half the cell area.

2.2 Extended algorithm

In order to understand the theoretical bound implied by the reuse partitioning technique, we extend the previous approach to enable more than one reuse distance. Hence we choose now two different reuse distances D_s and D_m in addition to $D_l = D$ ($D_s < D_m < D_l$) which must be compatible with the given array of base stations. Again, in order to guarantee the same SIR in each pair of co-channel cells, only a portion of each cell (a subarea) can be covered by carriers with reuse distance D_s and D_m. So we define two hexagonal subcells in each cell with the same center having radius R_s and R_m ($R_s < R_m < R_l$). The three non-overlapping cell subareas so identified are called *core* (the area inside the smallest hexagon), *middle* (the area inside the hexagon identified by R_m outside the core) and *ring* (the area in the cell outside core and middle). As in the case of only one cell partition, the relation between radius and reuse distance for each cell subarea is

$$\frac{D_s}{R_s} = \frac{D_m}{R_m} = \frac{D_l}{R_l} = \sigma \tag{9}$$

Once D_s and D_m have been selected given D_l, three different cell clusters are identified which include M_s, M_m and M_l cells respectively.

If η denotes now the ratio R_m/R_l, then

$$\eta = \frac{R_m}{R_l} = \sqrt{\frac{M_m}{M_l}} \tag{10}$$

The set F of carriers available in the network ($|F| = Q$) will be now partitioned into three subsets F_l, F_m and F_s, with cardinality Q_l, Q_m and Q_s, to be used with respective reuse distance D_l, D_m and D_s. The carriers in F_m are referred to as *medium haul frequencies* (*mhf's*). Hence each cell has available $q_l = Q_l/M_l$ lhf's, $q_m = Q_m/M_m$ mhf's and $q_s = Q_s/M_s$ shf's, summing up to a total number of carriers in the cell $q = q_l + q_m + q_s$.

The network capacity increase is computed as in the previous case of one cell partition only. Based on the same assumptions about user density in the area and even allocation of carriers to users, it follows that

$$\frac{q_s}{q} = \frac{R_s^2}{R_l^2} = \xi^2 \tag{11}$$

$$\frac{q_m}{q} = \frac{R_m^2 - R_s^2}{R_l^2} = \eta^2 - \xi^2 \tag{12}$$

$$\frac{q_l}{q} = \frac{R_l^2 - R_m^2}{R_l^2} = 1 - \eta^2 \tag{13}$$

Then the total number of carriers Q is given by

$$\begin{aligned} Q &= Q_s + Q_m + Q_l = \\ &= q_s M_s + q_m M_m + (q - q_s - q_m) M_l = \\ &= M_l q \left(\frac{M_s}{M_l} \frac{q_s}{q} + \frac{M_m}{M_l} \frac{q_m}{q} + 1 - \frac{q_s + q_m}{q} \right) = \\ &= M_l q (\xi^4 + \eta^2(\eta^2 - \xi^2) + 1 - \xi^2 - \eta^2 + \xi^2) = \\ &= M_l q (\xi^4 + \eta^4 - \eta^2 \xi^2 + 1 - \eta^2). \end{aligned} \quad (14)$$

The function $C(\xi, \eta) = q'/q$ to be minimized is now

$$C(\xi, \eta) = \xi^4 + \eta^4 - \eta^2 \xi^2 + 1 - \eta^2 \quad (15)$$

whose minimum is $(\xi = \sqrt{1/3}, \eta = \sqrt{2/3})$. Therefore the capacity increase factor in the network is $C^{-1}(\sqrt{1/3}, \sqrt{2/3}) = 1.5$ (50% additional bandwidth is available). Owing to the physical meaning of ξ and η, the optimum cell partition occurs again when core, middle and ring have the same area, each equal to one third of the basic cell area.

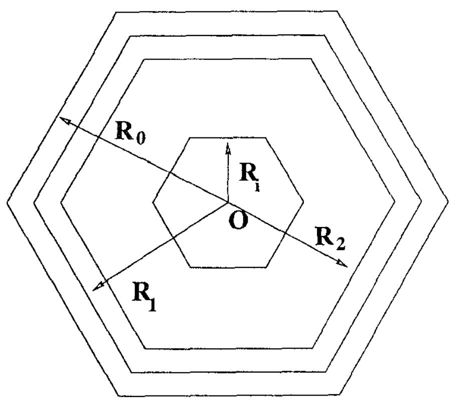

Figure 2: Cell with infinite partitions.

Let us now consider the case of a cell with $P-1$ partitions so that P non-overlapping areas are identified in each cell. Let R_i $(i = 0, 1, ..., P-1)$ denote the cell radius of the concentric hexagonal cells with decreasing length, R_0 being the basic cell radius (see Fig.2). Here the P non-overlapping subareas of the cell ($P-1$ rings and one core) are identified by selecting two adjacent radius values, say R_i and R_{i+1} for the subarea i^{th}, which has available q_i carriers. M_i denotes then the number of cells in the cluster associated to subarea i^{th} and $\xi_i = R_i/R_0$ $(i = 0, ..., P-1)$. An extrapolation of the previous results obtained for $P = 2$ and $P = 3$, stating that all cell subareas have the same area, gives the optimum cell partitioning defined by

$$\xi_i^2 - \xi_{i+1}^2 = \frac{1}{P} \qquad (i = 0, ..., P-2) \quad (16)$$

Accordingly we select the number of carriers for the i^{th} cell subarea as $q_i = q(\xi_i^2 - \xi_{i+1}^2)$. The total number of carriers Q is now expressed as

$$Q = \sum_{i=0}^{P-1} M_i q_i = \sum_{i=0}^{P-1} M_0 \xi_i^2 (\xi_i^2 - \xi_{i+1}^2) q = \quad (17)$$

$$M_0 q \sum_{i=0}^{P-1} \xi_i^2 (\xi_i^2 - \xi_{i+1}^2) \quad (18)$$

with the function $C(\xi_i, P)$ to be minimized

$$C(\xi_i, P) = \sum_{i=0}^{P-1} \xi_i^2 (\xi_i^2 - \xi_{i+1}^2) \quad (19)$$

By applying Eq. 16, after some algebraic manipulations we obtain

$$C(P) = \frac{P+1}{2P} \quad (20)$$

with a bandwidth increase factor $C^{-1}(P) = 2P/(P+1)$. Therefore in the theoretical limiting case of infinite cell partitions, the bandwidth increase factor becomes

$$\lim_{P \to \infty} C^{-1}(P) = 2$$

(the available bandwidth is thus doubled). Fig.3 shows the function $C^{-1}(P)$.

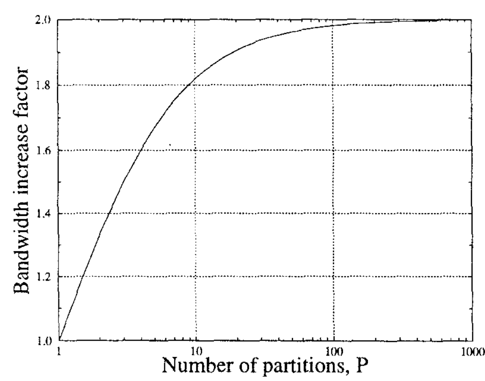

Figure 3: Maxiumum capacity increase.

2.3 Application of the algorithm

It is worth studying how the most important traffic performance parameter, the call blocking probability Π_b, is affected with reference to each of the two regions ring and core. Our simplifying assumptions are

- the q_s and q_l carriers, each supporting w channels (time-slots), are assigned according to the *FCA* technique to be exploited by users located in the core and ring respectively;

- users are uniformly distributed in the network, N per cell, each of them being a memoryless ON-OFF source characterized by a mean idle period of $1/\lambda$ and a mean busy period of $1/\mu$.

By means of standard Markovian analysis, the call blocking probability in the ring (core) Π_{bl} (Π_{bs}) is computed using the Engset formula with $q_l \cdot w$ ($q_s \cdot w$) servers and $N_l = (1-\xi^2) \cdot N$ ($N_s = \xi^2 \cdot N$) users. The overall call blocking probability is straightforwardly given by

$$\Pi_b = \xi^2 \cdot \Pi_{bs} + (1-\xi^2) \cdot \Pi_{bl}. \qquad (21)$$

A numerical computation of the various call blocking probability figures is now given, assuming $\sigma = \sqrt{21}$, which implies $M_l = 7$, and $D_s = 3R_l$. It follows $M_s = 3$ e $\xi = \sqrt{3/7} = 0.655$ (the optimum partitioning would require $M_s = 3.5$). If we choose $Q = 140$ the above carrier partitioning criteria (Eq. 7) gives $q = 26.485$ with a capacity increase factor of about 32%. Hence $q_l = q(1-\xi^2) = 15$ and $q_s = q\xi^2 = 12$ (an approximation to the nearest integer values has been accomplished). The number of carriers per cell in a traditional cellular environment would be $q' = 20$. Fig.4 shows the call blocking probability for the net-

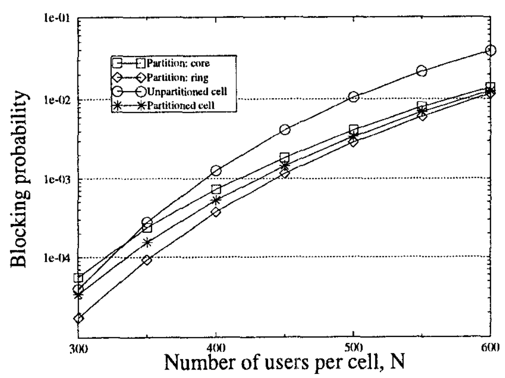

Figure 4: Blocking probability in partitioned cells.

work with and without reuse partitioning for the case of $1/\lambda = 4800s$ and $1/\mu = 120s$. This technique reduces the average Π_b but introduces unfairness in the service provided to core and ring users. These latter users receive a better service since the selected parameters imply a ring area larger than the core area. Since the number of servers is proportional to the size of the service area, the Engset formula provides this result.

Better performance and fairness can be achieved allowing core users to access time slots also on lhf's. However, sharing of the lhf's must be regulated somehow, otherwise the overall system behaviour can become really unfair to the detriment now of ring users. This problem is specifically analysed in [11]. Nevertheless, in this work we only deal with a DCA strategy, that allows free access of core users to lhf's, thus disregarding explicitly fairness issues.

3 Traffic and mobility models

The processes for the generation of user call and mobility are now described, by referring to the case of only one cell partition (each cell is divided into ring and core). The position of a mobile user is defined by the cell index where the user is actually found and by the subcell type (core or ring) within that cell. A simple mobility model is introduced to describe user movements among these service area subparts. We start considering a cell as a single entity. Let the cell crossing time be a random variable with negative exponential probability density function (pdf) and mean value $1/\gamma$. Let us assume first a spatially uniform user mobility. Therefore, the probability of finding a user in a given region is proportional to the region area. Let the service area be now split into S identical cells. Then, the mobility of a user can be modelled by the diagram in Fig.5 showing the transitions between a tagged cell and all the other $S-1$ cells. The outgoing

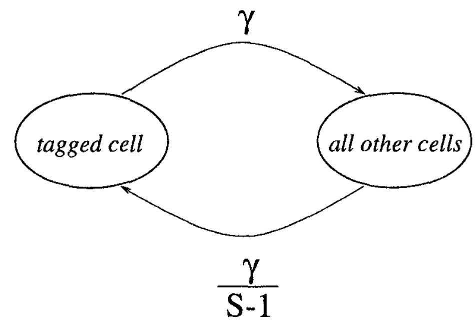

Figure 5: User mobility between cells.

transition rate from the tagged cell is known (γ), while the other transition rate is obtained by flow balance considering that the state probabilities are by definition $1/S$ (tagged cell) and $(S-1)/S$ (all other cells). When a user leaves the cell, he enters one of the six neighbouring cells, which is randomly chosen.

Now, to discriminate the user position between core and ring, we split the "tagged cell" state. To calculate the new transition rates, the following assumptions are made: the probability of finding a user in a given region is proportional to the region area, the transition rate toward the cell is unchanged, and the cell mean crossing time is proportional to the cell radius, i.e. the core mean crossing time is $1/\gamma_i = \xi \cdot 1/\gamma$. Fig.6 shows the resulting transition diagram considering again that the state probabilities are by definition ξ^2/S (core),

$(1-\xi^2)/S$ (ring), $(S-1)/S$ (all other cells).

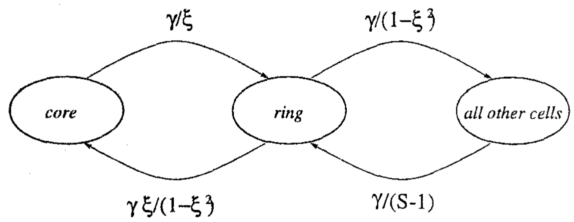

Figure 6: User mobility between sub-cells.

With regards to the generation of the traffic process, a user is modelled as a Markovian ON-OFF source. The user remains in the OFF (ON) state for a random time, t_{off} (t_{on}), with negative exponential pdf and $1/\lambda$ ($1/\mu$) as mean value. A call setup attempt corresponds to an OFF-ON transition. If the network can provide an idle channel the new call is accepted and the user holds the channel for the time t_{on}. Otherwise, the call setup is blocked and the user returns in the OFF state. During a call the user may cross either the cell border or the core-ring border and the current radio channel is no longer usable. Then a handover must be performed. If a new suitable channel cannot be found, a handover failure occurs and the call is dropped. The user is then forced into the OFF state.

4 Dynamic channel assignment policy

The basic procedures to handle carriers, that is the selection of the carriers to engage and to release, the management and swapping of the engaged carriers, are described in [12]. It has been shown that reuse partitioning and dynamic channel allocation result in an increase of the system bandwidth compared to the basic cellular system. Nevertheless core users accessing both shf's and lhf's, receive in general better service than ring users. In order to cope with this problem a simple feature is introduced: the *limited accessibility* of core users to lhf's. A threshold A ($A < 100$) is defined such that, if $f \cdot w$ channels can be currently supported in the cell by means of f lhf's carriers allocated to the cell, no more than $\lfloor Afw/100 \rfloor$ channels can be used by core users. $A = 0$ and $A = 100$ denote the limiting cases of complete partitioning of the carriers between cores and rings, and complete sharing of the lhf's between core and ring users.

Another feature that can improve the performance of the cellular network is the adoption of a FIFO queue in each base station that could buffer temporarily those new call requests that cannot be satisfied immediately due to the unavailability of both an idle slot in a carrier already allocated to the cell and of a new carrier to be assigned to the cell. Each of the queued users can then be served according to the FIFO policy as soon as an idle slot or a new carrier is made available in the cell. Adopting a call buffer means delaying temporarily the service provision to the user. Therefore a maximum buffering time must be suitably set so as to provide an acceptable quality of service.

5 Performance results

An open romboidal service area is considered. A regular array of 10x10 base stations provides radio coverage through omnidirectional antennas. Thus, we imagine the service area split into 100 identical hexagonal cells. The radio resource consists of a set of carriers, which can be assigned to cells independently of one another. Each carrier is organized in frames including a given number of time slots and each time slot supports a call. The minimum quantum of radio resource assignable to a cell is one carrier.

The call blocking probability given by the dynamic channel allocation algorithm with reuse partitioning described in the previous sections has been evaluated by means of computer simulation. It is always assumed here that users in the core have access also to carriers in the set F_l. The parameter A will denote the percent of lhf's channels that can be used by core users. We have selected the two cluster sizes $M_l = 7$ and $M_s = 3$. The network and traffic parameters assumed here are: $Q = 35$ carriers each holding $w = 4$ time-slots (channels), average traffic per user $\lambda/\mu = 0.025$ with mean holding time $1/\mu = 120s$.

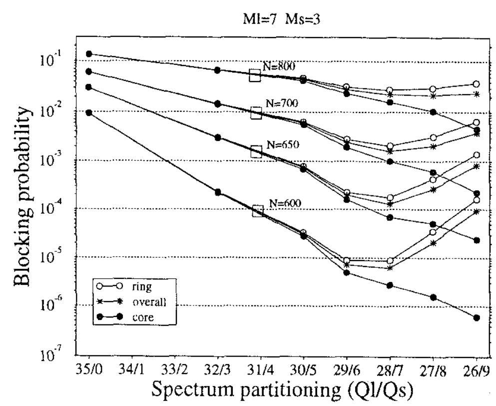

Figure 7: Fixed users: blocking probability vs number of users per cell.

Fig.7 shows the call blocking probability with fixed users, whose number N is the range 600-800, with a varying number of shf's Q_s (recall that the number of lhf's Q_l is given by $Q_l = Q - Q_s$). A better blocking performance is given by the reuse partitioning technique for all the values of spectrum partition compared to the basic case of no spectrum partition ($Q_s = 0$).

Depending on the number of users, the improvement ranges from one order to a few orders of magnitude. It is observed that there is an optimum splitting of the Q frequencies into the two sets Q_s and Q_l, which results to be $Q_l = 28$, $Q_s = 7$ for all the population sizes considered. However, as already mentioned in Section 2, the core users, in spite of the small number of carriers Q_s allocated to the core, experiment a lower blocking probability due to their accessibility to all the frequencies, whereas the ring users only access the lhf's. In spite of such unfairness, reuse partitioning still provides an improvement in the blocking probability even if the worst blocking performance, i.e. that experimented by ring users, is assumed as the overall system performance (see Fig.7).

We now add the feature of queueing at the base station so that a new call to be set-up by the station and blocked due to the unavailability of a suitable channel is queued for a limited time. A reasonable parameter for the call queueing time has been selected as 5 seconds, meaning that the call is dropped if neither a slot in an available carrier, nor a new carrier, is made available in the cell. A buffer for 30 calls has been assumed. The effect of call queueing and limited access to lhf's is now evaluated for a spectrum partition $Q_l = 28$, $Q_s = 7$ again without mobility. Fig.8

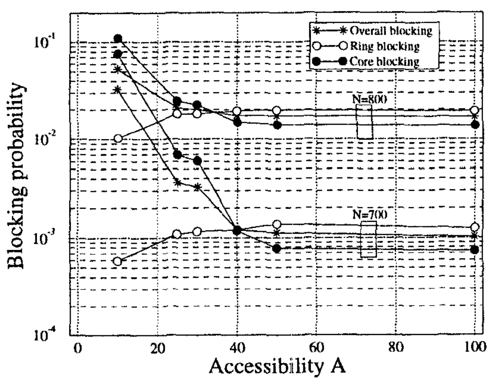

Figure 8: Fixed users: Blocking performance with limited access and queueing.

shows the overall blocking probability with queueing and with a variable access factor A compared to the basic case of no queueing full access ($A = 100$). Apparently the blocking probability increases as the accessibility factor A decreases. Nevertheless, a proper value for the accessibility factor to lhf's exists such that core and ring receive a comparable service with a small decrease of the overall blocking figure; in our case this occurs for A close to 40.

The user mobility is now added to the system with parameter $1/\gamma = 60s$. Now unsuccessful calls are due

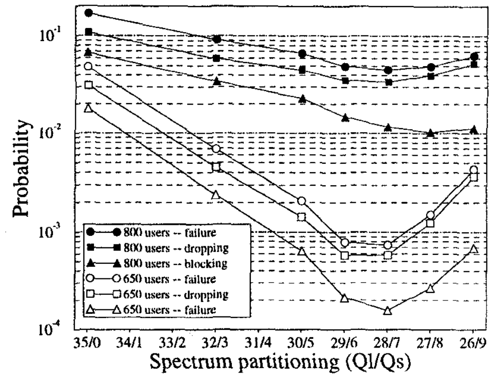

Figure 9: Moving users: loss probabilities vs spectrum partioning.

to two different events: blocking at call set-up-time or dropping due to unsuccessful handover. Note that with our reuse partitioning the handover is required both at cell border crossing and at core-cell border crossing when a lhf is being used to support the call. The *blocking probability* refers to the events of blocking of new calls, whereas the *dropping probability* accounts for unsuccessful handovers. The *failure probability* will denote the total blocking probability taking into account both type of failures. In this environment with mobile users all the probabilities shown in Fig.9 reach their minimum for the same splitting ratio of the $Q = 35$ frequencies into $Q_l = 28$ and $Q_s = 7$ which was obtained with fixed users. Again, even if not shown in the figures, core users receive a better service than ring users. Moreover Fig. 10 shows that the dropping probability during handovers due to cell-cell transitions is higher than the analogous due to core-ring transitions. Nevertheless, in the region of optimum spectrum partitioning, their values are comparable. Fig.11 gives

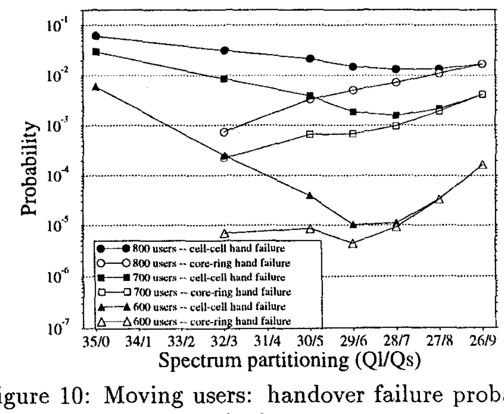

Figure 10: Moving users: handover failure probabilities vs spectrum partitioning.

the different probabilities for $N = 700$ users versus the spectrum partitioning in the region of optimum partition when the queue for buffering blocked new calls is available in the base station. The adoption of the buffer reduces significantly the unacceptance rate of new calls but makes the overall blocking performance decrease only very slightly. This is due to the dropping probability value which remains substantially the same: the queue has effect only on new call set-ups.

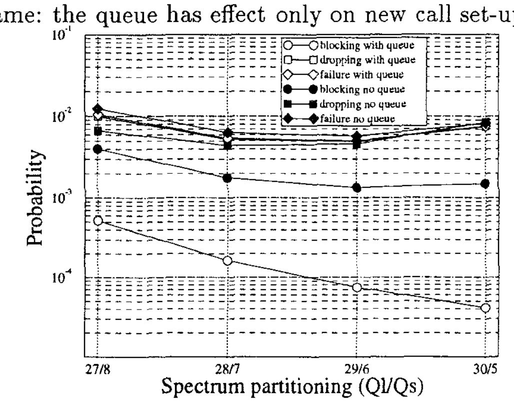

Figure 11: Moving users: effects of queueing on performance.

6 Conclusions

A new scheme for a more efficient use of radio resources in a circuit-switched cellular network has been described. Its basic idea is to define two or more sets of carriers with different reuse distances. Adopting such scheme only requires using different power levels for the transmission of the carriers in the two sets without increasing the number of base stations compared to an environment without spectrum partitioning. The upper bound of bandwidth increase factor in the network has been shown to be two. A remarkable improvement in the blocking probability has been obtained for all the network and traffic parameters considered. The scheme however introduces unfairness, meaning that such performance improvement is higher for core users than for ring users. This problem can be faced by limiting at a suitable threshold the access of ring users to lhf's. Using buffers to store temporarily the calls blocked due to channel unavailability has a limited impact on the overall failure probability, since handover events remain basically unaffected.

References

[1] S.Tekinay, B.Jabbari, "Handover and Channel Assignment in Mobile Cellular Networks", *IEEE Communication Magazine*, pp. 42-46, November 1991.

[2] H.Jiang, S.S.Rappaport, "CBWL With Fast Returning: a Channel Assignment Strategy for Cellular Communication Systems", *Proc IEEE ICUPC*, pp. 471-475, 1993.

[3] H.Jiang, S.S.Rappaport, "Prioritized Channel Borrowing Without Locking: a Channel Sharing Strategy for Cellular Communication", *Proc. IEEE GLOBECOM '93*, pp. 276-280, 1993.

[4] K.L.Yeung, T.-S.P.Yum, "Cell Group Decoupling Analysis of a Channel Borrowing Based Dynamic Channel Assignment Strategy in Microcellular Radio Systems", *Proc. IEEE GLOBECOM '93*, pp. 281-287, 1993.

[5] T.-S.P.Yum, W.-S.Wong, "Hot-Spot Traffic Relief in Cellular Systems", *IEEE Journal on Selected Areas in Communication*, Vol. SAC-11, pp. 934-939, August 1993.

[6] S.Nanda, D.J.Goodman, "Dynamic Resouce Acquisition: Distributed Carrier Allocation for TDMA Cellular System", *Proc. IEEE GLOBECOM '91*, pp. 883-889, 1991.

[7] S.S.Kuek, W.C.Wong, "Ordered Dynamic Channel Assignment Scheme with Reassignment in Highway Microcells", *IEEE Trans. Vehic. Tech.*, Vol. VT-41, pp. 271-277, August 1992.

[8] C.-L.I, "Distributed Dynamic Channel Allocation Algorithms in Microcellular Under Light Traffic Load", *Proc. IEEE ICC '93*, pp. 983-989, 1993.

[9] C.-L.I, P.-H.Chao, "Local Packing - Distributed Dynamic Channel Allocation at Cellular Base Station", *Proc. IEEE GLOBECOM '93*, pp. 293-301, 1993.

[10] W.C.Y.Lee, "Elements of Cellular Mobile Radio Systems", *IEEE Trans. Vehic. Tech.*, Vol. VT-35, pp. 48-56, May 1986.

[11] S.Papavassiliou, L.Tassiulas, P.Tandon, "Meeting QOS Requirements in a Cellular Network with Reuse Partitioning", *Proc. IEEE INFOCOM '94*, pp. 4-12, 1994.

[12] A.Pattavina, S.Quadri, V.Trecordi, "Reuse Partitioning in Cellular Networks with Dynamic Channel Allocation", *Proc. IEEE GLOBECOM '95*, pp. 1543-1548, Singapore, December 1995.

[13] J.Zander, H.Eriksson, "Asymptotic Bounds on the Performance of a Class of Dynamic Channel Assignment Algorithms", *IEEE Journal on Selected Areas in Communication*, Vol. SAC-11, pp. 926-933, August 1993.