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A Channel Sharing Scheme for Cellular Mobile Communications

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Abstract. This paper presents a channel sharing scheme, *Neighbor Cell Channel Sharing (NCCS)*, based on region partitioning of cell coverage for wireless cellular networks. Each cell is divided into an inner-cell region and an outer-cell region. Cochannel interference is suppressed by limiting the usage of sharing channels in the inner-cell region. The channel sharing scheme achieves a traffic-adaptive channel assignment and does not require any channel locking. Performance analysis shows that using the NCCS scheme leads to a lower call blocking probability and a better channel utilization as compared with other previously proposed channel assignment schemes.

Key words: channel assignment, neighbor cell channel sharing, cellular mobile communications.

1. Introduction

One of the major design objectives of wireless cellular communication systems is high network capacity and flexibility, while taking into account time-varying teletraffic loads and radio link quality. The limited radio frequency spectrum requires cellular systems to use efficient methods to handle the increasing service demands and to adapt system resources to various teletraffic (referred to as traffic) in different cells. Many current cellular systems use the conventional radio channel management, fixed channel assignment (FCA), where a set of nominal channels is permanently allocated to each cell for its exclusive use according to traffic load estimation, cochannel and adjacent channel interference constraints [1]. Due to the mobility of users, the traffic information is difficult to accurately predict in any case. As a result, the FCA scheme is not frequency efficient in the sense that the channel assignment cannot adapt to the dynamically changing distribution of mobile terminals in the coverage area. In order to overcome the deficiency of FCA, various traffic-adaptive channel assignment schemes have been proposed, such as dynamic channel assignment (DCA) [2]-[4] and hybrid channel assignment (HCA) [5]. In centralized DCA schemes, all channels are grouped into a pool managed by a central controller. For each call connection request, the associated base station will ask the controller for a channel. After a call is completed, the channel is returned to the channel pool. In distributed DCA schemes, a channel is either selected by the local base station of the cell where the call is initiated, or selected autonomously by the mobile station. A channel is eligible for use in any cell provided that signal interference constraints are satisfied. Since more than one channel may be available in the channel pool to be assigned to a call when required, some strategy must be applied to select the assigned channel. Although the DCA schemes can adapt channel assignment to dynamic traffic loads, it can also significantly increase network complexity due to cochannel cell locking and other channel management, because it is a call-by-call based assignment. In order to keep both cochannel interference and adjacent channel interference under a certain threshold, cells within the required minimum channel reuse distance from a cell that borrows a channel from the central pool cannot use the same channel. DCA also requires fast real-time signal processing and associated channel database updating. A compromise between the radio spectrum efficiency and channel management complexity is HCA, which combines FCA with DCA. In HCA, all available channels are divided into two groups, FCA group and DCA group, with an optimal ratio. It has been shown that both DCA and HCA can achieve a better utilization of radio channel resources than FCA in a light traffic load situation, due to the fact that both schemes can adapt to traffic load dynamics. However, they may perform less satisfactorily than FCA in a heavy traffic load situation due to the necessary channel locking [2, 5]. Another approach to adaptive channel assignment is channel borrowing, in which the channel resources are divided into borrowable and non-borrowable channel groups [6, 7]. The non-borrowable group is assigned to a cell in the same way as FCA. When all of its fixed channels are occupied, a cell borrows channels from its neighbor cells which have a light traffic load. More recently, a channel borrowing scheme called channel borrowing without locking (CBWL) is proposed [8], where the C channels of each base station are divided into seven distinct groups. The C_0 channels of group 0 are reserved for exclusive use of the given cell. The ($C_i,\ i = 1, 2, \ldots, 6$) channels of the other six groups can be borrowed by the six adjacent cells respectively, one group by one adjacent cell. Each borrowing channel is used with a limited power level. That is, the borrowed channel is directionally limited as well as power limited. Therefore, the channel locking for cochannel cells is not necessary.

In this paper, we propose a channel sharing scheme based on a channel sharing pool strategy. The scheme can adapt to traffic dynamics so that a higher network capacity can be achieved. The method partitions cell coverage region to eliminate the cochannel interference due to the dynamic channel sharing; therefore, it does not need any channel locking. In addition, because the borrowable channels are a portion of total available channels and are shared only among adjacent cells, the channel sharing management is relatively simple as compared with that of DCA and HCA. Compared with the CBWL borrowing scheme, the advantage of the newly proposed scheme is the relaxed constraint on directional borrowing, which results in a higher degree of traffic adaptation and a lower call blocking probability. This paper is organized as follows. In Section 2, after studying the cochannel interference issue, we calculate the cochannel interference spatial margin for cell region partitioning, and then propose the *Neighbor Cell Channel Sharing* (NCCS) scheme for traffic adaptive channel assignment. The adjacent channel interference using the NCCS scheme is also discussed. In Section 3, the call blocking probability using the NCCS scheme is derived. Numerical analysis results are presented in Section 4, which demonstrate the performance improvement of the NCCS over that of previously proposed schemes including FCA, HCA, and CBWL. The conclusions of this work are given in Section 5.

2. The Neighbor Cell Channel Sharing (NCCS) Scheme

A. Cochannel Interference

A cellular network employs distance separation to suppress cochannel interference. Figure 1 shows the frequency reuse strategy for a cellular system with frequency reuse factor equal to 7, where the shadowed cells are the cochannel cells of Cell_(17) using the same frequency channels (as an example). We assume that the received carrier-to-interference ratio (CIR) at a

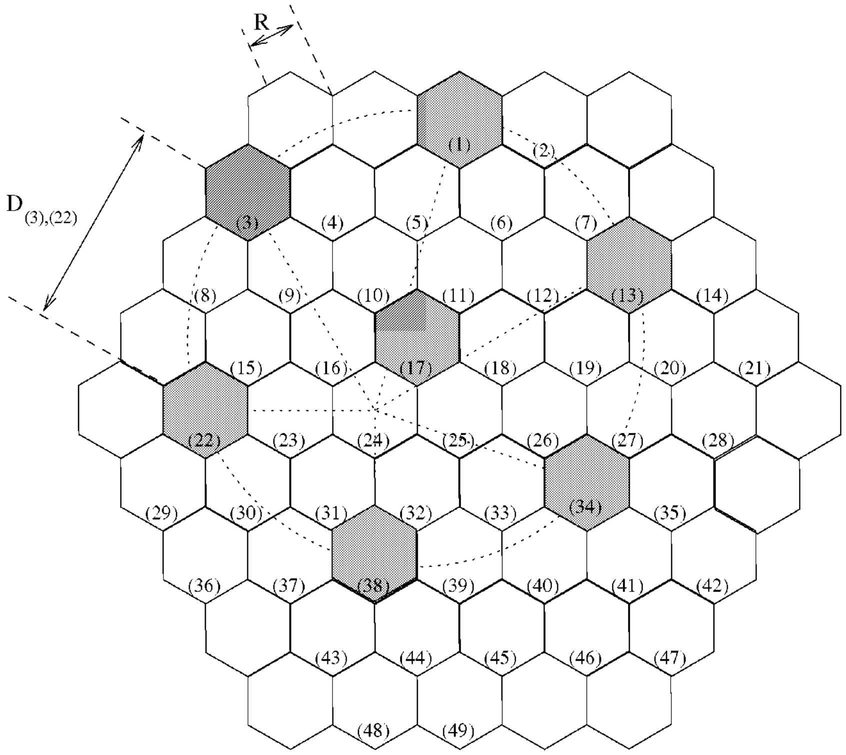

Figure 1. Cochannel interfering cells in a cellular network.

mobile station (e.g., in Cell_(17)) caused by the base stations in the cochannel cells is, on the average, the same as the CIR at the base station of Cell_(17) caused by the mobile stations in the cochannel cells. The CIR can be calculated by [9]

$$\text{CIR} = \frac{1}{\sum_{i=1}^{k} (\frac{D_i}{R})^{-\gamma}} = \frac{1}{\sum_{i=1}^{k} q_i^{-\gamma}} \tag{1}$$

where R is the radius of each cell, D_i is the distant between the interested cell and its ith cochannel cell, $q_i = D_i/R$, and γ is a propagation path-loss slope determined by the actual terrain environment (usually γ is assumed to be 4 for cellular radio systems). In a fully equipped hexagonal cellular system, there are always six cochannel cells in the first tier. It can be shown that the interference caused by cochannel cells in the second tier and all other higher-order tiers is negligible as compared with that caused by the first tier cochannel cells [10]. As a result, if we consider the cochannel interference only from the cells in the first tier, $k = 6$ and $q_i = q$ for $i = 1, 2, \ldots, 6$ in equation (1), where q is a constant.

In order to achieve a probability of at least 90% that any user can achieve satisfactory radio link quality for voice service, it requires that the CIR value be 18 dB or higher, which corresponds to $q = 4.6$ for $\gamma = 4$. If a channel of Cell_(17) is lent to any of its six neighbor cells, then the cochannel interference to and from any of the six cochannel cells in the first tier may increase. For example, if a channel of Cell_(17) is lent to Cell_(24), the distances between cochannel cells will be $D_{(24),(38)} = 3R$, $D_{(24),(34)} = 4.6R$, $D_{(24),(13)} = 6R$, $D_{(24),(1)} = 6R$, $D_{(24),(3)} = 5.2R$, and $D_{(24),(22)} = 3.5R$. The shortest one is $3R$. The channel borrowing of Cell_(24) from Cell_(17) reduces the CIR value of the channel in Cell_(24) from 18 dB to

16 dB, if R is kept unchanged. A similar degradation on radio link quality also happens in Cell_(38), where the CIR value is reduced to 17.4 dB. The decrease of the CIR value is due to the decrease of the q_i values.

B. Cell Region Partition

From the above discussion, we conclude that any reduction of the q_i value due to a channel borrowing will degrade the radio link quality, because a channel borrowing will result in a decrease of some D_i values. One way to keep the q_i value unchanged even with channel borrowing is to reduce the value of R accordingly when D_i is reduced, which can be implemented by reducing the transmission power. By reducing R to R_r ($\overset{\triangle}{=} \eta R$ with $0 < \eta < 1$), a borrowed channel can be used only inside the circle (called the inner-cell region) centered at the base station with radius equal to R_r in all cochannel cells. In other words, each cell is divided into two regions, the inner-cell region and the rest (called the outer-cell region). For example, if Cell_(24) borrows a channel from Cell_(17), with $D_{(24)(38)} = 3R$, η should be 0.652 in order to ensure that $q_i \geq 4.6$. Since $D_i \geq 3R$, the overall CIR value will be greater than 18 dB. Correspondingly, all the C channels of each base station are also divided into two groups: one consists of N nominal channels to be used exclusively in the cell (in both the inner-cell and outer-cell regions), and the other consists of the rest S $(= C - N)$ sharing channels to be used in the inner-cell regions of the given cell and its six neighbor cells. For each cell, there is a pool of sharing channels to be used in its inner-cell region. The sharing pool consists of all the available sharing channels of the cell and the neighbor cells.

C. The Proposed Channel Sharing Scheme

In the following, it is assumed that: *(i)* all base stations work in the same condition: omnidirection antennas are used, and transceivers are available at a given carrier frequency; *(ii)* only cochannel interference and adjacent channel interference are considered, and all other kinds of noise and interferences are neglected; and *(iii)* neighbor cells can communicate with each other. Without loss of generality, Figure 2 shows the flowchart of the channel assignment for a two-cell network, where “CH” stands for “channel”. Using NCCS, the channel resources in each cell consist of N nominal channels to serve the users in the whole cell as conventional FCA and S sharing channels to serve users in the inner-cell regions. When a call connection is requested, a nominal channel will be assigned to it. In the case that all the nominal channels of the cell are occupied, if the mobile is in the inner-cell region, then a channel from the sharing pool will be used; otherwise, if the mobile is in the outer-cell region and there is a mobile in the inner-cell region using a nominal channel, then an event of channel swapping occurs: the inner-cell mobile switches to a channel from the sharing pool and gives up its original nominal channel to the new call from the outer-cell region. The purpose of the channel swapping is to make room for new calls so that the system channel resources can be fully deployed. Note that when there is no channel available in the sharing pool, channel swapping may be carried out in a neighbor cell to allow for channel borrowing. The call will be blocked if *(i)* all the nominal channels are occupied and no channel swapping is possible when the mobile is in the outer-cell region; *(ii)* all the nominal channels and sharing channels in the pool are occupied when the mobile is in the inner-cell region. When a connected user moves from the outer-cell region into the inner-cell region, the transmitters of both mobile terminal and base station will reduce the transmitting power automatically since the mobile terminal gets closer to the base

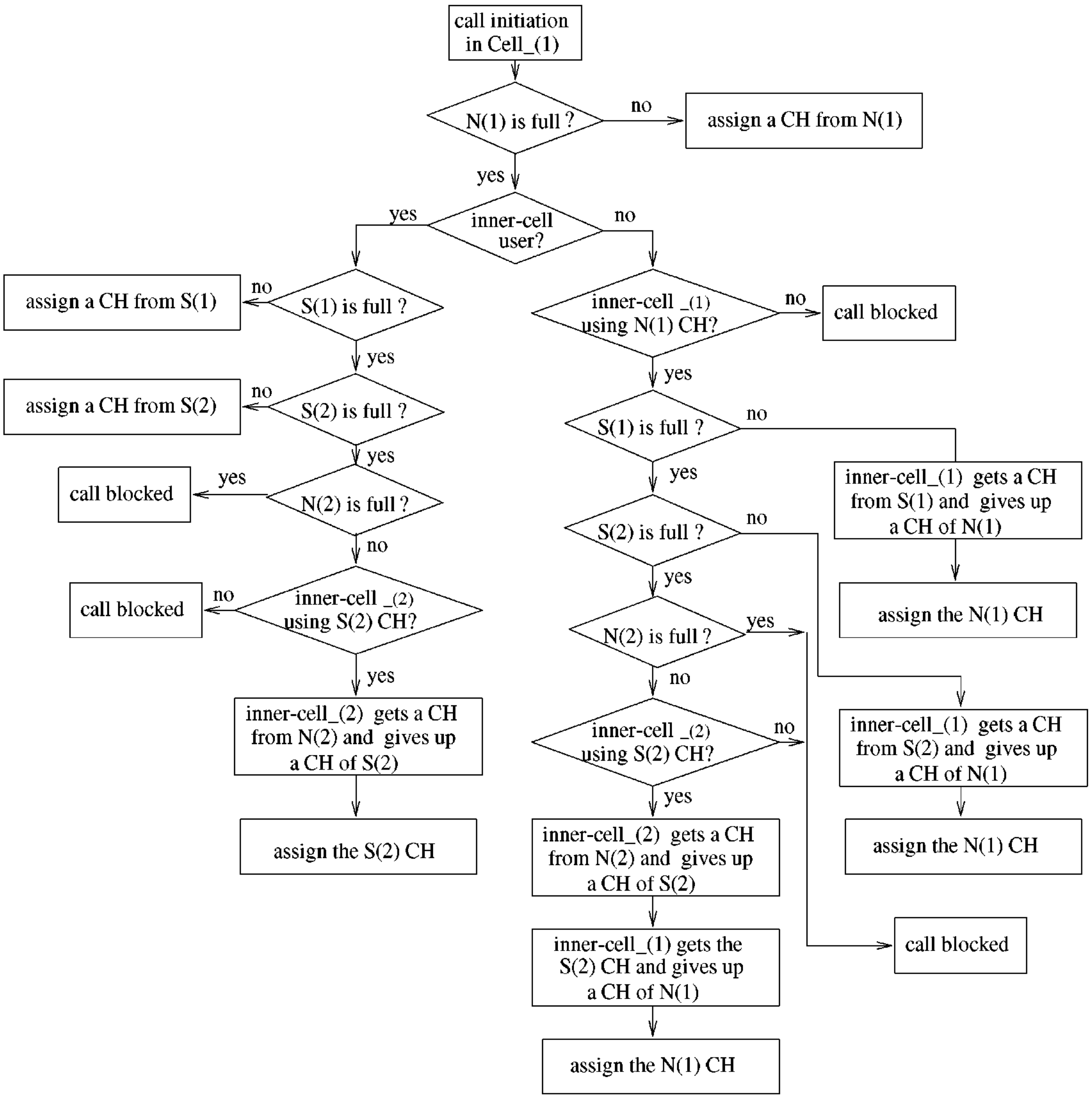

Figure 2. Flowchart of the neighbor cell channel sharing (NCCS) scheme.

station. When an inner-cell mobile terminal using a sharing channel moves into the outer-cell region, not only the associated power control occurs, but also an intra-cell handoff happens because the sharing channel cannot be used in the outer-cell region. If there is no nominal channel available for the intra-cell handoff, the link will be forced to drop.

In implementing the NCCS, each borrowable channel has an "on/off" register in the associated channel sharing pools to indicate whether the channel is available. During the channel borrowing from a neighbor cell, the borrowed channel register is turned to "off" in the sharing pools. For example, when Cell_(24) borrows a channel from Cell_(17), the channel register is turned "off" in the sharing pools of Cell_(17), Cell_(10), Cell_(11), Cell_(16), Cell_(18), and Cell_(25). When the borrowed channel is returned, the register is then turned back to "on" in the pools. One aspect that should be taken into account is the potential borrowing conflict, that is, two adjacent cells try to borrow the same channel from the different cells at the same time. This will violate the channel reuse distance limitation. To prevent the borrowing conflict, some selective borrowing algorithms should be introduced such as borrowing with ordering [11], borrowing from the richest [12]. The cell selectivity for borrowing can achieve higher capacity at the expense of higher complexity. One simple approach is to use directional borrowing restriction. For example, in Figure 1, when Cell_(24) borrows a channel from Cell_(17), it is required that Cell_(23) not borrow the same channel from Cell_(22), and Cell_(31) and Cell_(32) not borrow the same channel from Cell_(38). All other neighbor cells of the six cochannel cells are allowed to borrow the same channel. In order words, the borrowing restriction is limited only to those cells affected by the borrowing of Cell_(24) from Cell_(17). The restriction can be implemented by turning "off" the register of the channel in the sharing pools of Cell_(23), Cell_(31) and Cell_(32). It should be mentioned that in the CBWL scheme [8], directional lending is used to avoid the borrowing conflict, where each cell can borrow up to one sixth of the borrowable channels from its neighbor cells. As a result, using the NCCS scheme each cell has a much larger channel sharing pool than that using the CBWL scheme under the same condition of the channel resource arrangement. It is expected that the NCCS scheme can adapt channel assignment to traffic dynamics to a larger extent as compared with the CBWL scheme, leading to a lower call blocking probability.

D. Adjacent Channel Interference

Adjacent channel interference is a result of the splatter of modulated RF signals. Because the mobility of network users, the distance between a mobile terminal and its base station changes with time. At each moment, some mobile terminals are close to the base station and others are not. Considering the receiver at the base station, the adjacent channel interference may not be a problem if the signals from the desired channel and both its adjacent channels are received with the same power level. The bandpass filter of the receiver should provide adequate rejection to the interference from the adjacent channels. However, the problems may arise if two users communicate to the same base station at significantly different transmitting power levels using two adjacent channels. Signal from the adjacent channel can be stronger than that from the desired channel to such a degree that the desired signal is dominated by the signal carried by the adjacent channel. This situation is referred to as "near-far" effect in wireless mobile communication systems. The larger the difference between the near-far distances, the worse the adjacent channel interference in radio links. Severe adjacent channel interference may occur when the difference in the received power levels exceeds the base station receiver's band rejection ratio. Therefore, channel separations are required, which is primarily determined by the distance ratio, the path-loss slope γ, and the receiver filter characteristics. The required channel separation, in terms of channel bandwidth W, is $2^{G-1}W$ [9], where $G = (1/L)10\log_{10}(d_a/d_b)^{\gamma}$, L in dB is the falloff slope outside the passband of the receiver bandpass filter, d_a is the distance between the base station and mobile terminal M_a using the desired channel, and d_b is the distance between the base station and mobile terminal M_b using one of the adjacent channels. In order to overcome the adjacent channel interference, FCA achieves channel separation by channel interleaving in such a way that there is sufficient channel guard band between any two channels assigned to a base station. For a call connection, the user can just randomly choose any channel with the strongest signal from all the available channels, without violating the adjacent channel interference constraint.

With channel borrowing, if a cell has traffic congestion, it will borrow channels from its neighbor cell(s). A borrowed channel may be located in the channel guard band, which can introduce excessive interference to the desired signal when the difference between d_a and d_b is large. Therefore, two aspects need to be taken into account with channel borrowing: one is the cochannel interference issue as to whether channel borrowing is allowed; the other is the adjacent channel interference issue as to whether the borrowed channel can provide satisfactory link quality. For the NCCS, it has been shown that with dynamic power control, if $d_a/d_b \leq 16$, no extra channel separation is required between any two channels assigned to the same base station in order to overcome the adjacent channel interference [10]. If we consider the users, M_a and M_b, both in the inner-cell region, then the requirement $d_a/d_b \leq 16$ is eqivalent to that the radius of the inner-cell $R_r \leq 16R_0$, where R_0 is the minimal distance between a mobile terminal and the base station. Under the condition, no channel spacing is needed among the sharing channels used in the inner-cell regions. With the cell radius $R = R_r/0.652$ for $\gamma = 4$, adjacent channel interference does not affect the channel interleaving and the target radio link quality when channel borrowing happens in the NCCS operation as long as $R_0 \geq 0.04075R$.

Compared with other channel assignment schemes, the NCCS scheme offers the following advantages: *(i)* it ensures satisfactory link quality (taking into account both cochannel interference and adjacent channel interference) for both nominal channels and borrowable channels, which cannot be achieved using directed retry and its enhanced schemes [6]; *(ii)* it does not need global information and management of channel assignment which is required when using DCA schemes, resulting in simplicity of implementation; *(iii)* each base station is required to operation on its nominal channels and the borrowable channels of its sharing pool, which is a much smaller set as compared with that when using DCA schemes; and *(iv)* no channel locking is necessary, which leads to a better utilization of the channel resources and a simpler management for channel assignment as compared with DCA and HCA.

3. Performance Analysis

In the following performance analysis of the NCCS scheme, we consider that the network operates on a blocked call cleared (BCC) basis, which means once a call is blocked it leaves the system. Under the assumption that the number of users is much larger than the number of channels assigned to a base station, each call arrival is independent of the channel occupancy at the base station [13]. Handoff calls are viewed as new calls.

A. Basic Modeling

In general, requests for radio channels from mobile users can be modeled as a Poisson arrival process. The occupancy of radio channels at a base station conventionally is considered as a “birth and death” process with states $\{0, 1, \ldots, C\}$, where C is the number of total channels assigned to the base station. A new call arrival enters the system with a mean arrival rate λ and leaves the system with a mean departure rate μ. Defining the traffic density $A = \lambda/\mu$, it can be derived that the probability of the channel occupancy being at state j is [13]

$$P_j(A, C) = \frac{A^j/j!}{\sum_{k=0}^{C} A^k/k!}, \quad j = 0, 1, \ldots, C. \tag{2}$$

From Equation (2), the probability of radio channel resource congestion (i.e., the call blocking probability) is

$$P_B(A, C) = \frac{A^C/C!}{\sum_{k=0}^{C} A^k/k!} \tag{3}$$

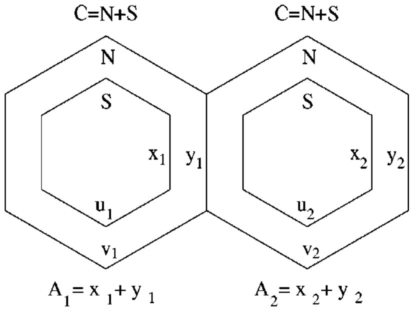

Figure 3. Topology for channel sharing between two cells.

which provides a fundamental measure of the mobile cellular network performance. Equation (3) is usually referred to as *Erlang's B formula* [13].

B. Call Blocking Probability with Channel Sharing

In order to formulate the call blocking probability for the NCCS scheme, we consider the channel sharing between two adjacent cells without loss of generality. Both base stations are equipped with the same numbers of nominal channels and borrowable channels respectively. The uniform topology of this scenario is shown in Figure 3. For Cell_(i) (where $i = 1$ and 2), x_i represents the traffic density in the inner-cell region; y_i the traffic density in the outer-cell region; $u_i \in \{0, 1, 2, ..., C + S\}$ the channel occupancy in the inner-cell; and $v_i \in \{0, 1, 2, ..., , N\}$ the channel occupancy in the outer-cell. We assume that u_i and v_i are independent random variables. For each cell, the channel occupancy in the inner-cell region may be different from that in the outer-cell region, so is the call blocking probability. Let $P_B(C_{1,in})$ and $P_B(C_{1,out})$ denote the blocking probability of Cell_(1) for inner-cell and outer-cell regions respectively. Due to the channel sharing, the blocking probabilities of Cell_(1) depend on the channel occupancy of the neighbor cell, Cell_(2), which is at one of the following two states:

(I) The Cell_(2) channel occupancy is within its C equipped channels. In this case, we say that Cell_(2) is *underflow* with $a \in \{0, 1, ...S\}$ unused and borrowable channels. The probability of Cell_(2) being *underflow* is

$$P(C_{2,u}) = P(0 \leq u_2 + v_2 \leq C) = \frac{\sum_{j=0}^{C} (x_2 + y_2)^j / j!}{\sum_{k=0}^{C+S} (x_2 + y_2)^k / k!}; \tag{4}$$

(II) The Cell_(2) channel occupancy is over its assigned C channels. In this case, we say that Cell_(2) is *overflow* with $b \in \{1, ...S\}$ borrowed channels from Cell_(1). The probability of Cell_(2) being *overflow* is

$$P(C_{2,o}) = P(C + 1 \leq u_2 + v_2 \leq C + S) = \frac{\sum_{j=C+1}^{C+S} (x_2 + y_2)^j / j!}{\sum_{k=0}^{C+S} (x_2 + y_2)^k / k!}. \tag{5}$$

It can be verified that $P(C_{2,u}) + P(C_{2,o}) = 1$.

For state (I), the blocking probability of the outer-cell region of Cell_(1) (represented by outer_cell_(1) for simplicity) is

$$P_B(C_{1,outer} | C_{2,u}) \;=\; P(v_1 = N) P(u_1 \leq S)$$

$$+\sum_{a=0}^{S}\sum_{k=0}^{N} P(v_1 = N-k)P(u_1 = S+k+a)$$
$$P(u_2+v_2 = C-a). \tag{6}$$

The call blocking probability of the inner-cell region of Cell_(1) (represented by inner-cell_(1)), $P(C_{1,\text{inner}}|C_{2,u})$, is not only conditioned upon Cell_(2) channel occupancy, but also upon the situation of outer-cell_(1). If there are n unused channels out of the N nominal channels in Cell_(1), the inner-cell users can use them. Under the assumption that the channel occupancies in outer_cell_(1) and Cell_(2) are independent, we have

$$P(C_{1,\text{inner}}|C_{2,u}) = \sum_{a=0}^{S}\sum_{n=0}^{N} P(u_1 = S+n+a)P(v_1 = N-n)P(u_2+v_2 = C-a). \tag{7}$$

For state (II), the blocking probability of the outer_cell_(1) is

$$\begin{aligned} P_B(C_{1,\text{outer}}|C_{2,o}) \;=\; & \sum_{b=0}^{S}[P(v_1 = N)P(u_1 < S-b) \\ & + \sum_{k=0}^{N} P(v_1 = N-k)P(u_1 = S+k-b)]P(u_2+v_2 = C+b). \end{aligned} \tag{8}$$

and the blocking probability of the inner_cell_(1) is

$$P_B(C_{1,\text{inner}}|C_{2,o}) = \sum_{b=0}^{S}\sum_{n=0}^{N} P(v_1 = N-n)P(u_1 = S+n-b)P(u_2+v_2 = C+b). \tag{9}$$

Using Equation (2) to compute $P(u_i = j) = P_j(x_i, N+2S)$, $P(v_i = j) = P_j(y_i, N)$ and $P(u_i + v_i = j) = P_j(x_i + y_i, N+2S)$ for $i = 1$ and 2, the four conditional probabilities of Equations (6)-(9) can be obtained. Then, using Equations (4)–(5) the blocking probabilities of both inner-cell and outer-cell regions of Cell_(1) can be calculated according to the theorem on total probability

$$\begin{aligned} P_B(C_{1,\text{outer}}) \;&=\; P_B(C_{1,\text{outer}}|C_{2,u})P(C_{2,u}) + P_B(C_{1,\text{outer}}|C_{2,o})P(C_{2,o}) && (10) \\ P_B(C_{1,\text{inner}}) \;&=\; P_B(C_{1,\text{inner}}|C_{2,u})P(C_{2,u}) + P_B(C_{1,\text{inner}}|C_{2,o})P(C_{2,o}). && (11) \end{aligned}$$

C. Effect of User Mobility

Taking user mobility into consideration, the number of mobile terminals in a cell at a given moment is a random variable. For the two-cell network, the overall traffic load is dynamically distributed over the two cells. The network is designed in such a way that each cell has a fair share of resources depending on its traffic load in a long term. However, the traffic load over each cell is a random process. Let A_i ($\overset{\triangle}{=} x_i + y_i$) denote the total traffic density of Cell_(i) for $i = 1$ and 2, and $\tilde{A}$ ($\overset{\triangle}{=} A_1 + A_2$) the overall traffic density of the cellular network. Given the number of subscribers, the traffic of the whole network, $\tilde{A}$, is a constant. Let $A_1 = \alpha\tilde{A}$ and $A_2 = (1-\alpha)\tilde{A}$, where $\alpha \in [0, 1]$ is a random variable referred to as a *traffic load distributor* whose value indicates the traffic load in Cell_(1) and Cell_(2). If Cell_(1) and Cell_(2) are identical (Figure 3), the traffic load distributor should have a mean value $E(\alpha) = 0.5$. The following relations are considered for the blocking probability equations: $x_i = \rho_i A_i$ and $y_i = (1 - \rho_i)A_i$ for $i = 1$ and 2, where $\rho_i \in [0, 1]$ (referred to as an *interior distributor* inside Cell_(i)) is a random variable with a mean value of

$$E(\rho_i) = \frac{\text{coverage of inner-cell}(i)}{\text{coverage of whole cell}(i)} = 0.425, \quad i = 1, 2.$$

Using these two distributors, the blocking probabilities in equations (10)-(11) can be denoted as

$$P_B(C_{1,\text{outer}}) = g(\alpha, \rho_1, \rho_2; \tilde{A}, N, S) \tag{12}$$

$$P_B(C_{1,\text{inner}}) = h(\alpha, \rho_1, \rho_2; \tilde{A}, N, S) \tag{13}$$

where $g(\cdot)$ and $h(\cdot)$ denote any measurable function. If we assume that mobile terminals are uniformly distributed in the coverage area and the cell sizes are the same, then $\rho_1 = \rho_2 = \rho$. Furthermore, the number of terminals in each cell or cell region follows a binomial distribution, from which we can obtain the joint probability distribution function $p(\alpha, \rho)$ of the distributors α and ρ. As a result, the blocking probabilities related to the overall traffic density $\tilde{A}$ and the design parameters N and S are

$$P_{B,C_{1,\text{outer}}}(\tilde{A}; N, S) = \sum_i \sum_j g(\alpha_i, \rho_j; \tilde{A}, N, S) p(\alpha_i, \rho_j) \tag{14}$$

$$P_{B,C_{1,\text{inner}}}(\tilde{A}; N, S) = \sum_i \sum_j h(\alpha_i, \rho_j; \tilde{A}, N, S) p(\alpha_i, \rho_j). \tag{15}$$

In reality, cellular network service operators will try to achieve service fairness, that is, appropriate channel resources will be allocated to each base station in order to obtain the same call blocking probability over all the cells in the service area. Therefore, the system is designed to have

$$\begin{aligned} P_{B,C_{1,\text{inner}}}(\tilde{A}, N, S)|_\alpha &= P_{B,C_{1,\text{outer}}}(\tilde{A}, N, S)|_\alpha \\ &= P_{B,C_{2,\text{inner}}}(\tilde{A}, N, S)|_\alpha \\ &= P_{B,C_{2,\text{outer}}}(\tilde{A}; N, S)|_\alpha \\ &\triangleq P_{B,NCCS}(\tilde{A}, N, S)|_\alpha. \end{aligned} \tag{16}$$

As a result, the blocking probabilities in terms of the traffic density $\tilde{A}$ and channel resources N and S is

$$P_{B,NCCS}(\tilde{A}, N, S) = \sum_i P_{B,NCCS}(\tilde{A}, N, S)|_{\alpha_i} p_\alpha(\alpha_i) \tag{17}$$

where $p_\alpha(\alpha_i)$ is the probability distribution function of α. The analysis for the two-cell network can be extended to a multiple-cell network as shown in Figure 1, where for a cell under consideration all of its 6 neighbor cells can be equivalently modeled by a composite neighbor cell.

4. Numerical Results and Discussion

The numerical analysis in this section is to provide a performance comparison between the NCCS and other channel assignment schemes. The following assumptions are made in the analysis: *(i)* All the base stations are equipped with the same numbers of nominal channels and borrowable channels respectively; *(ii)* Each new call is initiated equally likely from any cell and is independent of any other calls. Except in the analysis of the bounds of the blocking probability, the following assumptions are also made: *(iii)* Taking into account the possible borrowing conflict, the channel sharing pool for each cell consists of available borrowable channels of the cell and four of its neighbor cells; *(iv)* The traffic loads in all the cells are statistically the same. Under the assumptions, given the total traffic loads in the network, the traffic load distributor for the cell under consideration follows a binomial distribution.

Figure 4 shows the call blocking probabilities of the FCA, HCA [5] and NCCS schemes. In FCA, each base station has 28 nominal channels; in HCA, each base station has 20 FCA channels and 8 DCA channels; and in NCCS, $N = 20$, $S = 8$. In Figure 4 and all the following figures, A is the traffic density for each cell. The performance of the FCA scheme is calculated based on Equation (3), while the performance of the NCCS scheme is based on Equation (17). It is observed that: *(i)* At a low traffic load, HCA has a much lower blocking rate than FCA; however, as the traffic load increases, the advantage of HCA over FCA disappears. In fact, HCA may have a higher blocking probability, due to the necessary DCA channel locking; *(ii)* The NCCS scheme outperforms the HCA scheme because the NCCS scheme can adapt to traffic dynamics without channel locking; *(iii)* The NCCS scheme performs much better than the FCA scheme, but the improvement is reduced as the traffic load increases. This is because with a large value of A, all the cells tend to be in a congestion state, so that the probability of having any sharing channel available for borrowing is greatly reduced.

Figure 5 shows the blocking probabilities of the FCA, CBWL with channel rearrangement [8] and NCCS schemes. In the CBWL scheme, each base station has 24 channels with $C_0 = 6$ and $C_i = 3\ (i = 1, 2, \ldots, 6)$, and 30% of call arrivals can use borrowed channels. In the NCCS scheme, $N = 18$ and $S = 6$, corresponding to 25% of calls can use borrowed channels. It is observed that the NCCS scheme has a lower blocking probability than the CBWL scheme, due to the fact that the CBWL is limited to the directional lending, resulting in a channel sharing pool with much less borrowable channels as compared with that of the NCCS scheme.

The call blocking probability of the NCCS scheme depends on the traffic load dynamics, which can be difficult to generalize. In the following, we consider two extreme cases which lead to the lower and upper bounds on the call blocking probability for the NCCS scheme with channel sharing among $m\ (= 2, 3, 4, 5, 6, 7)$ neighbor cells. First, consider the situation where one cell is a traffic "hot spot" and its neighbor cells have many idle channels, which we refer to as a *local burst* situation. The heavily traffic loaded cell can borrow most or all of the sharing channels from its neighbor cells, resulting in a lower bound of blocking probability for the cell. The other situation is that all the cells are heavily loaded and no channel sharing is possible, which is referred to as a *global busy* situation. If the channel resources, C, in each cell is properly divided into the nominal channel group and sharing channel group, then the global busy situation results in the upper bound of the call blocking probability of the NCCS scheme, which is the same as the call blocking probability of the FCA scheme. Figure 6 shows the lower and upper bounds of the call blocking probability of the NCCS scheme with channel sharing among m multiple cells. Each base station has 15 nominal and 5 sharing channels. It is observed that the lower bound decreases significantly as m increases, due to an

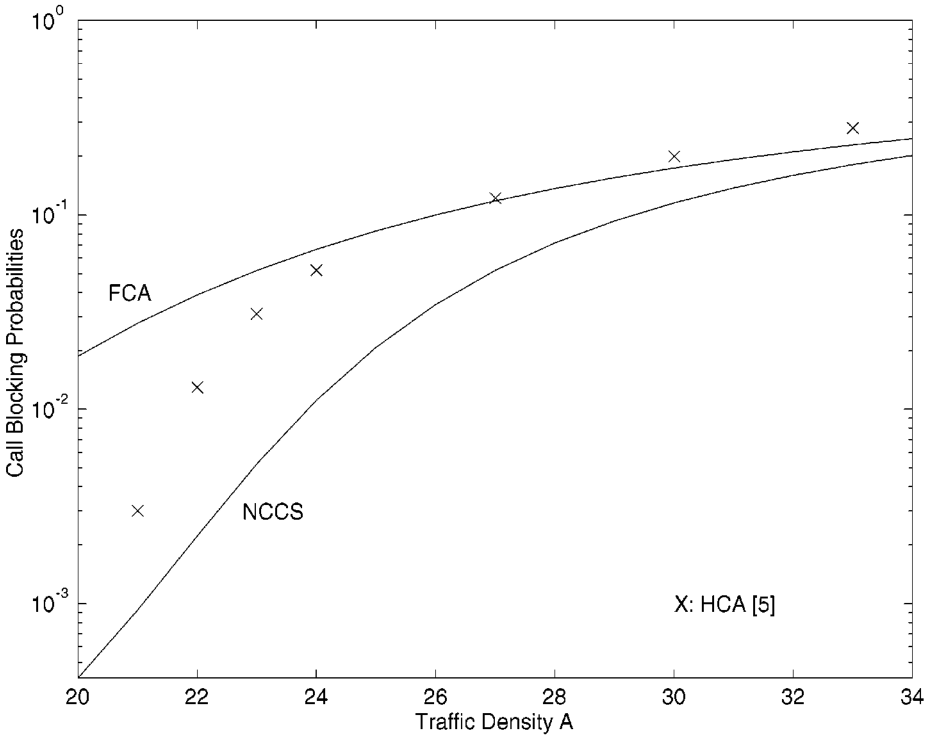

Figure 4. Call blocking probabilities of FCA, HCA and NCCS.

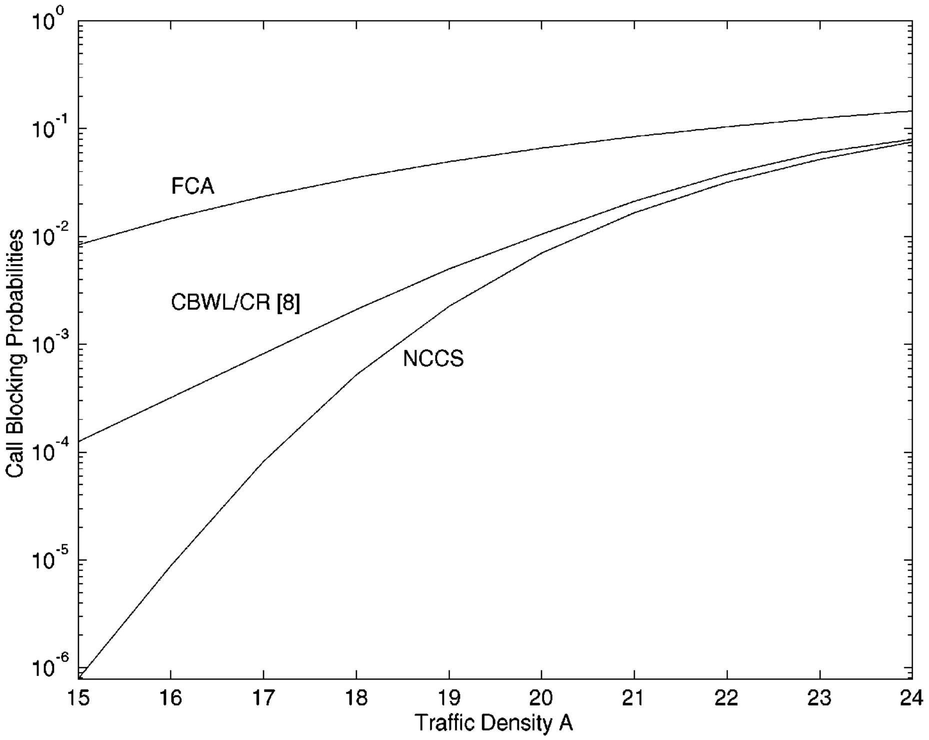

Figure 5. Call blocking probabilities of FCA, CBWL and NCCS.

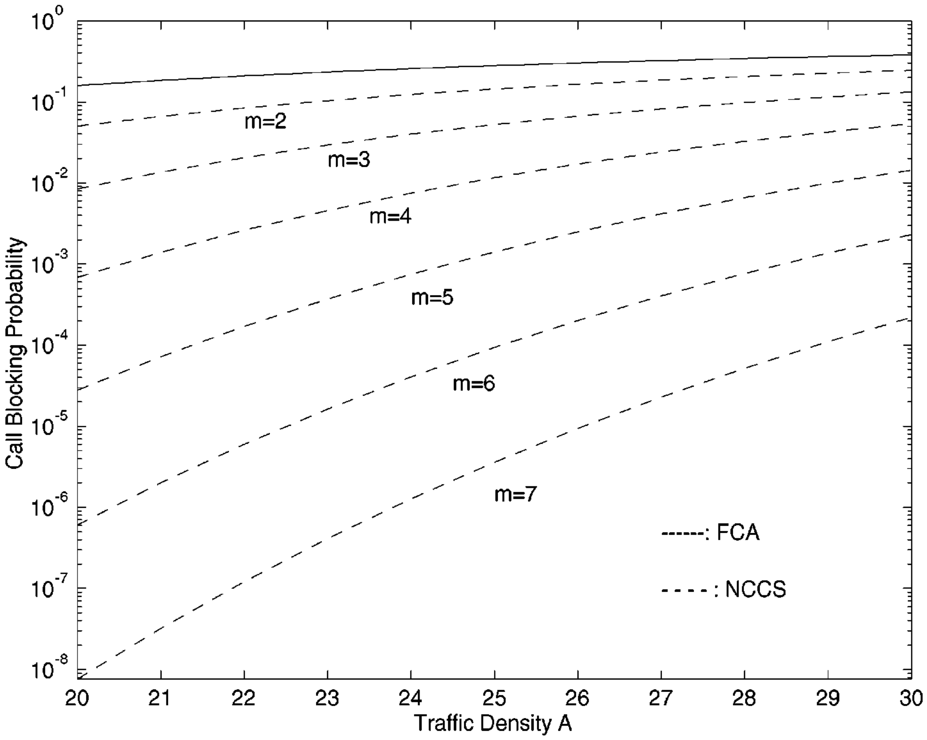

Figure 6. Bounds of the NCCS call blocking probability with channel sharing among m cells.

increased number of sharing channels available in the sharing pool. However, when the traffic density increases, the performance improvement of the NCCS over FCA (the upper bound) is significantly reduced. Even with all the sharing channels from the m neighbor cells, it is still possible that the channel resources available to the cell are not enough to provide service to all the incoming calls in the hot spot.

5. Conclusions

In this paper, we have developed the neighbor cell channel sharing (NCCS) scheme for wireless cellular networks. Both cochannel interference and adjacent interference issues regarding the channel sharing have been discussed. It has been shown that the NCCS scheme achieves a lower call blocking probability for any traffic load and traffic dynamics as compared with other channel assignment schemes. The performance improvement is obtained at the expense of additional intra-cell handoffs. With more neighbor cells in channel sharing, the proposed scheme offers better traffic handling capacity. The advantages of the proposed scheme include *(i)* that no channel locking is necessary, and *(ii)* larger channel sharing pools are available due to less strict constraint on directional borrowing, which lead to both simpler channel resource management and lower call blocking probability.

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