Distributed Channel Allocation Algorithm with Power Control

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ABSTRACT

In this paper, we integrate the channel assignment and power assignment into a distributed channel access algorithm. A cost-function is introduced to provide some optional channels according to their cost for transmitted power level searching. The simulation results show that this algorithm largely increases capacity compared with the fixed channel allocation (FCA). The proposed algorithm can adapt to the call saturated state of network and does not cause high intracell handover access. It has a short average call setup time even at high traffic loads. We suggest that the intracell handover rate should be a factor in evaluation of an algorithm’s performance, because high handover access will intensively increase the load of switch and cause much higher call dropping and blocking probabilities than those we expect.

I. INTRODUCTION

In recent years, as the number of subscribers to the mobile radio system has been growing rapidly, increasing the capacity of this system, i. e., the number of subscribers per area (or volume) unit at some predefined level of service quality, is one of the key issues of mobile communications. The traditional channel allocation method, the fixed channel allocation (FCA), is not very efficient for utilization of available spectrum, and impractical in microcell communication systems, because the large number of cells, irregularities in propagation and traffic distributions make pre-allocation of channels almost impossible. Dynamic channel allocation (DCA) had long been pursued as the answer for coping with time and spatial variations of traffic demand in communication networks.

Any DCA algorithm would be classified as a timid DCA algorithm or as an aggressive DCA algorithm. For the aggressive DCA algorithm, assigning a channel to a new call might result in call-drop of on-going calls. A DCA scheme minimizing the call outage probability, in order to minimize the call drop probability, has been proposed [1]. The power control can suppress the adjacent channel interference (for non-orthogonal channels), the cochannel interference (for orthogonal channels), and minimize power consumption to extend terminal battery life. Undoubtedly, the power control can raise the network capacity. To establish a new radio link the system has to assign: a) an access base station (BS); b) a pair of channels for signal transmission in downlink and uplink; c) a pair of transmitter power for the BS and MS. The key issue of such a radio resource allocation is to allocate channels to calls as possible without resulting in dropping of on-going calls. J. Zander [2], G. J. Foschini [3] have developed some power control algorithms based on the idea of balancing the SIRs on all radio links, but the final SIR achieved by this algorithm may be unsatisfactory for some of links. Some calls must be dropped in order to keep SIRs of other calls higher than the predefined threshold value. Obviously, the channel assignment is highly correlative with the power control. The combination of DCA and power control in obtaining some substantial capacity gains has been reported [4], but inadvertent dropping of calls caused by originating calls is not much treated. In addition, an exhausted searching scheme let it impractical for call setup. In this paper, a distributed channel allocation algorithm is proposed based on a cost function.

II. DYNAMIC CHANNEL AND POWER ASSIGNMENT ALGORITHM

A. Cost of Channel Assignment

The control of channel access and power control may be combined into a channel management policy. According to simulation by G. J. Foschini and Z. Miljanic [4] inadvertent dropping of calls caused by originating calls can occur so often that all unsuccessful (blocked or dropped) calls are unintentionally dropped calls and not blocked calls. In addition, an exhausted searching and too frequent intracell handover access (average 220% as much as the new call access in their scheme) will decrease the system capacity and make it difficult to implement into real network. A fully distributed scheme will reduce the complexity of system, but such kind of algorithm is always very aggressive. Properly selecting a channel and transmitted power will reduce the aggressiveness and reduce the call drop probability. Since uplink and downlink channels are assumed not to interfere each other; in principle, there is no big difference between downlink and uplink in channel allocation, we only consider the downlink situation in following.

COST FUNCTION

When a new call is accepted into the network, it might cause quality deterioration of on-going calls. The cost of a call admission depends on the assigned channel l for this call, the distance D_i between cell centers of co-channel users of channel l, the location (r_i, θ_i) of all cochannel users, and the transmitted power set $P \in P_i$ $(i \in n)$, of all cochannel users. The cost function will be:

$$C = C(P_i, r_i, \theta_i, l, D_i), \; i \in n. \tag{1}$$

However, the power control is in the sense of local optimization of interference probability in the aspect of the transmitted power, the transmitted power is not considered as a factor of the cost function C in this paper.

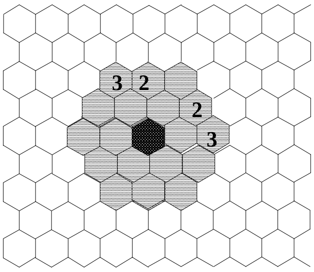

Figure 1 Simulation network.

⬢-host cell, ⬡ - interfering cells.

For any cell, normally, only two tiers of cells are considered as its interfering cells. If a cochannel user is assigned in the host cell, for the second tier of interfering cells (Fig. 1), the co-channel interference to cells of type 3 ($q = D/R = 2\sqrt{3}$) is different from that to cells of type 2 ($q = D/R = 3$). As shown in Fig. 2, the downlink cochannel interference power of mobile i in cell k from a mobile j in cell h is:

$$I_j = P_j d_{ih}^{-\alpha} 10^{\xi/10}, \tag{2}$$

where $d_{ih} = (D^2 + r^2 - 2Dr\cos\varphi)^{1/2}$; P_j is the transmitted power of mobile j; ξ is the slow fading variable with log-normal distribution. If assumed that the mobile users are uniformly distributed within a cell, the average interference power with respect to the whole cell area in cell i is:

$$\begin{aligned}\bar{I} &= \iint_A I_j f(A)\,dA \\ &= R^{-\alpha} P_j \int_0^{2\pi}\int_0^{R} E\left[10^{\xi/10}\right]\left(\frac{R}{d_i}\right)^{\alpha} \frac{1}{\pi \mathrm{R}^2}\, r\,dr\,d\varphi . \end{aligned} \tag{3}$$

By numeric calculation, for $\alpha = 4$, the average interference for $D/R = 3$ and $D/R = 2\sqrt{3}$ is respectively:

$$\bar{I} = R^{-\alpha} P_j E\left[10^{\xi/10}\right] \cdot \frac{C}{\pi}, \tag{4}$$

$$\text{where } C = \begin{cases} 0.1363 & \text{for } \quad D/R = 3 \\ 0.0736 & \phantom{\text{for }} \quad D/R = 2\sqrt{3} \end{cases} .$$

From (4), it can be seen that the average interference with the distance $D = 3R$ is approximately twice as much as that in the distance $D = 2\sqrt{3}R$. If ignoring the difference of $E[10^{\xi/10}]$ between different cells, and only considering the variable D in (4), we can assume the average interference to a cochannel user in type 2 interfering cells is almost twice as much as that in type 3 interfering cells. That means that, if assigning a new user in the host cell, the cost to the cochannel user in type 2 interfering cells is almost twice as much as that in type 3 interfering cells.

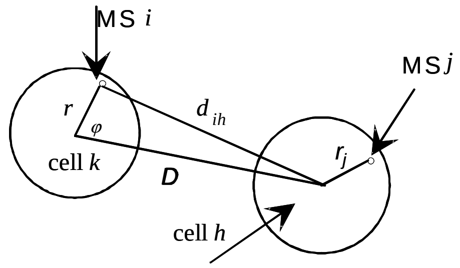

Figure 2. Downlink interference.

We use the average interference as a clue to construct a cost function for channel allocation. For cell x, denote $F(x)$ as the available channel set in cell x, $H(k)$ as the occupied channel set in interfering cell k, $I_1(x)$ as the set of the first-tier of interfering cells, $I_{22}(x)$ as the set of the second-tier of type 2 interfering cells, and $I_{23}(x)$ as the set of the second-tier of type 3 interfering cells (Fig. 1). We define the cost to the interfering cell $k \in \{ I_1(x), I_{22}(x), I_{23}(x) \}$, due to allocating channel $l \in F(x)$ in cell x, as

$$C_x(k,l) = \begin{cases} 0 & \text{if } \; l \notin H(k) \\ c & \text{if } \; l \in H(k) \text{ and } k \in I_1(x) \\ 2 & \text{if } \; l \in H(k) \text{ and } k \in I_{22}(x) \\ 1 & \text{if } \; l \in H(k) \text{ and } k \in I_{23}(x) \end{cases}, \tag{5}$$

where the constant c is defined as a large value in order to avoid assigning a cochannel user in the first-tier of interfering cells as possible. The overall cost function to its interfering cells for channel l is

$$C_x(l) = \sum_{k \in \{I_1(x), I_{22}(x), I_{23}(x)\}} C_x(k,l) \; . \tag{6}$$

From (6), we can calculate the cost of each available channel in cell x. The cost of a channel roughly describes its effects on the on-going calls, if this channel is allocated. We will use the cost to decide the priority of a channel. The lower the cost of a channel, the higher the priority of the channel for allocation.

B. Power Assignment

All channels used in the system are assumed to be orthogonal channels and only co-channel interference is considered. The call is established with the base station from which the call receives the strongest signal. Assume that channel p is assigned to a call in cell i. For the downlink, let coefficient g_{ik} (>0) denote the link gain on the path from cell i to cell k. If the transmitter power of base station (BS) in cell i is T_i (>0), then the received power in cell i is $g_{ii}T_i$. Suppose that the same channel is reused in cell

k with the transmission power T_k, then $g_{ik}T_k$ becomes the amount of co-channel interference from cell k. The signal to interference ratio (SIR) is:

$$SIR_i = \frac{g_{ii}T_i}{\sum_{k=1}^{N} g_{ik}T_k - T_i g_{ii} + V} = \gamma_i \ , \qquad (7)$$

$$i = 1, 2, ..., N \ ,$$

where N is the number of co-channel users in a system and V is the additive noise level. If there exists a power vector $\boldsymbol{T} = [T_1, T_2, ..., T_N]^t$, such that $\gamma_i \geq \gamma$ for $i = 1, 2, ..., N$ (where γ is threshold value of SIR), the allocation of channel p is achievable. Finding or achieving an optimal power vector $\boldsymbol{T}$ is the task of the power control. We use following distributed power control algorithm to search for a locally optimal power for the new call:

$$\boldsymbol{T}(0) = T_{min} \ ,$$

and

$$T_i(k+1) = min\{\ \eta_i(k) * T_i(k), T_{max}\} \ , \qquad (8)$$

where $\eta_i(k) = \gamma / \gamma_i(k)$; $T(0)$ and $T(k)$ denote the initial and the k-th discrete time transmitted power vector respectively; T_{min} and T_{max} are the minimum and maximum transmitted power respectively. This power control algorithm is also used to maintain the quality of on-going calls.

C. Channel Allocation Algorithm

Quickly making decisions on the access channel and transmitted power are key issues of quality of service (QoS). We integrate the channel assignment and power assignment into a distributed channel access algorithm. To reduce the call drop rate and to shorten the call set-up time, all available (free) channels are evaluated by each base station, and some optional channels are provided according to their priorities for transmitted power level searching. The cost function in equation (6) is used to decide the priority of a channel. The lower the cost of a channel, the higher the priority of the channel. The highest priority of a channel has the highest priority for call set-up probation.

The calculation of channel cost is based on the local information about current state of channel occupancy in the cell's vicinity (two tiers of cells). Every cell has a list of the priority for all available (free) channels. The priority of available channels in each base station is updated (real time) after a call is accepted or terminated (drop or departure) in its interfering cells. The proposed algorithm is operated in the following way:

- For any cell, two tiers of cells are considered as interfering cells (Fig. 1). The channel state information (allocating or releasing) of each cell is locally exchanged to its interfering cells. Every cell maintains a priority list of its available channels according to their cost. The lower the cost of a channel, the higher the priority of this channel. The priority list is updated (real time) after a call is accepted or terminated in its interfering cells. In order to avoid as possible assigning a cochannel user in the first tier of interfering cells, we choose the constant c in (5) as 13. To reduce the aggressiveness of the algorithm, if the cost of a channel is high than 23 (not more than one cochannel user in the first-tier cells), the channel is marked in order not to allow its use for call set-up.

- When a call arrives in a cell, the highest priority (lowest cost) channel is chosen for call set-up probation. The power control algorithm in Eq. (8) is used to check if this channel can be assigned to the new call. That is, a pilot signal is transmitted with the power controlled by Eq. (8). At the same time, the received power of the pilot signal and interference are measured to check if this channel can be accepted for service. If the SIR is higher than the predefined value, the channel is used for service with this transmitted power. If the maximum power is requested, or the iterations of power level adjustment is larger than the allowed value (chosen as 10 here), but the SIR is still lower than the predefined value, switch to another channel with the next highest priority for probing, and so on. Actually, an exhaustive searching scheme is not allowed in real system. Hence, we prescribe that if four channels have been probed, but the SIR requirement is still not satisfied, the call is blocked.

- If a call is in service, the power control algorithm in Eq. (8) is used to maintain its quality. Each base monitors its own served calls at some amount of time interval. We assume that all base stations are synchronised. When a call's SIR falls below the target value, the power control procedure is requested. However, if the maximum transmitted power is requested or the iterations of power level adjustment are larger than the allowed value, but the SIR is still below a specified value, the handover procedure is requested. The "call set-up" procedure will begin to search for a channel for handover. If a channel is found, the call is moved to this channel. Otherwise, the call is dropped.

III. SIMULATION MODELS

The performance of this algorithm is investigated by simulations. In these simulations, the network model is a two-dimensional regular hexagonal grid with 81 cells (9×9) (Fig. 1). In order to avoid the boundary effect, the left-most and the right-most columns are "neighbours" with each other, and so are the top and the bottom rows. Thus, the results are representative of an infinite system, and therefore may be applied to a large network. Around a host cell, only two tiers' cells (6 cells in the first tier and 12 cells in the second tier) are considered to be interfering cells. The channel model is assumed as an average pathloss with an inverse fourth power ($\alpha = 4$) distance dependency, and log-normal slow fading with zero mean value and a $\sigma = 8$ dB standard deviation. There are 36 orthogonal channels available in the system. The cell radius is 5 km. The maximum and minimum transmitted powers are 20 and 0.02

Watts respectively (30 *dB* range). Assume all channels in all cells have a -120 *dBm* noise level at the receivers. The threshold value of SIR for assigning a channel to a new call and the target value of ongoing calls both are chosen as γ = 12 *dB*. The threshold value for call dropping is 10 *dB*.

Omnidirectional antennas are assumed to be used in the system. The call arrival in each cell is an independent Poisson process with uniform arrival rate. The duration of each call is exponentially distributed with a mean of 120s. Locations of calls are randomly generated within each cell.

IV. SIMULATION RESULTS

The purpose of this algorithm is mainly to maximize the number of mobiles that can be assigned into a network and minimize the call drop rate of on-going calls. In addition, the efficiency of the algorithm is also considered. If an algorithm achieves lower block probability by causing intensive random intracell call handover, it is still questionable. Because of the limitation of the system processing capacity (including computing, measuring capacity, ect.) in real network, such an algorithm would create higher probabilities of call block and drop than those from simulations. To evaluate the system performance, two extra parameters, R_h, the intracell handover rate, and R_{uh}, the unperformed-handover rate, are defined as:

$$R_h = \frac{\text{number of requests of intracell handover access}}{\text{number of admitted calls}},$$

$$R_{uh} = \frac{\text{number of unperformed handover calls in successful calls}}{\text{total number of successful calls}}$$

The physical meaning of R_h is the average number of intracell handover accesses caused by admitting a new call. In following simulations, the number of call arrivals varies from 175,000 to 218,000 depending on the traffic load. The SIR of each served call is measured once per second. If the SIR of an on-going call is deteriorated lower than the target value 12 *dB*, the power control procedure is called. If the maximum transmitted power is requested or the iterations of power level adjustment have been 10, but the SIR is still below 10 *dB*, the handover procedure is requested. If there is not a qualifying channel for handover, the call is dropped.

The blocking and dropping probabilities for different traffic load (uniform) are shown in Fig. 3. The blocking probabilities of fixed channel allocation (FCA) with reused size of three (N = 3) are also shown. We find that at the load of approximately 9.4 Erlangs our scheme performs with 1% blocking and 1.2% dropping probabilities while FCA shows about 9.7% blocking probability. The system capacity has achieved quite good improvement compared with FCA.

The DCA used this cost-function in (6) has shown [5] outperformed the first available (FA) and the minimum SIR (MSIR) DCA schemes (no handover and power control). It has lower dropping and unsuccessful call (blocking and dropping) probabilities. Therefore, this cost-function based DCA algorithm is not so aggressive. The results of handover rate will give more support to this statement.

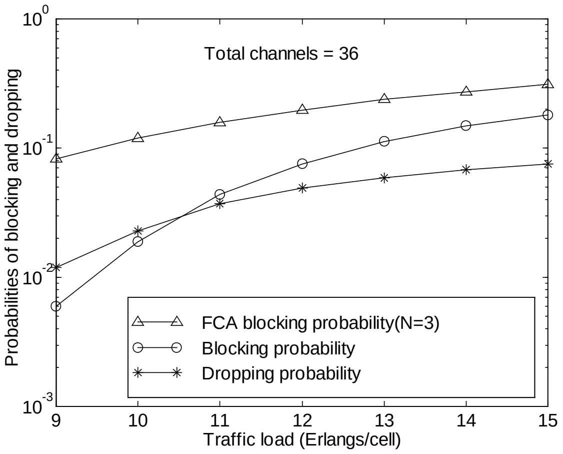

Figure 3. Probabilities of blocking and dropping with uniform traffic loads.

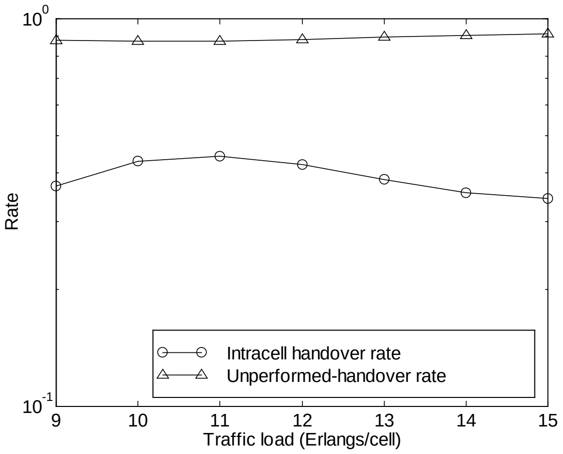

Figure 4. The intracell-handover rate and unperformed handover rate with uniform traffic loads.

The intracell handover rate is shown in Fig. 4. It varies from 34.3% to 44.1%. The results are very interesting that the handover rate initially increases with traffic load increment, but for traffic loads over 11 Erlangs it decreases with the traffic load increment. The reason might be that: the dropping and blocking probabilities increase with the traffic load increment; for high traffic load, while the calls in network reach a value, the system controls the call admission and only those not so aggressive calls are allowed into network (Fig. 3 shows that there is a cross-point between the curves of the blocking probability and the dropping probability). The unperformed handover rate (Fig. 4) gives more evidence for this explanation. The unperformed handover rate varies slightly from 87.5% to 91.4%. It initially decreases with increasing the traffic load, but for traffic loads over 11 Erlangs it increases with increasing the traffic load. Therefore, this channel allocation algorithm can adapt to the call saturated state of network and does not cause a series of call handover.

In order to evaluate the speed of call setup, we simulate how many allocated channels (allocated to new calls or handover calls) are from channels with the highest priority (called number 1) and the second highest priority (called number 2). Figure 5 shows the percentage of allocated channels in the location of the priority list with different traffic loads. More than 98% allocated channels are from the highest and next highest priority channels. That means that 98% allocated channels, have undergone the set-up probing with one or two channels after those channels are found to satisfy the SIR requirement. The number of allocated channels from the highest priority channels slightly increases at high traffic loads. This algorithm is designed to search channels for call set-up from the first four highest priority channels whose cost is not larger than a specified value, but most of them are from the first two highest priority channels. Hence, this algorithm performs with a short call setup time and at high traffic loads the average time is slightly shorter than that at low traffic loads.

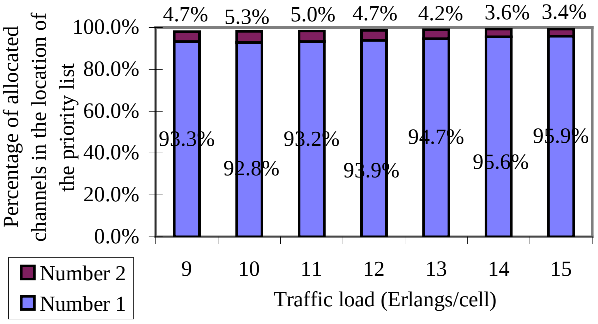

Figure 5. Percentage of allocated channels in the location of the priority lists. Number 1 is denoted the highest priority channels and number 2 is denoted the next highest priority channels.

Comparing the performance of our algorithm with the algorithm which does not have any priority channels for call setup probation and just randomly chooses any free channels. If the chosen channel does not satisfy the SIR requirement, another free channel is randomly chosen to perform the same procedure until the SIR requirement is satisfied or the call is blocked [4]. Because of the long simulation time, we only simulate the latter case at 15 Erlangs traffic load. Even though the latter algorithm has 0.5% blocking probability and 4.2% droping probability, the intracell handover rate is 696% and the unperformed handover rate is 66.3%. That means that average 6.96 intracell handover accesses are caused by an admitted call; almost 34% successful calls are supported by intensive handover. In addition, only 72.8% and 10.2% allocated channels, have undergone set-up probing with one and two channels respectively after those channels are found to satisfy the SIR requirement. Because of the limited processing capacity in practical system, such huge intracell handover might not be acceptable and must cause much higher call block and drop probabilities than those from simulated results. Hence, the intracell handover rate should be a factor to evaluate the performance of an algorithm. In addition, the latter algorithm has a longer call setup time.

V. CONCLUSIONS

In this paper, we have presented a distributed channel access algorithm combining the channel assignment and power assignment. A cost-function, has been introduced to provide some optional channels according to their cost for transmitted power level searching.

The simulation results show that this algorithm largely increases the capacity compared with the fixed channel allocation (FCA). We find that at the load of approximately 9.4 Erlangs our scheme performs with 1% call block and 1.2% call drop probabilities while FCA (N=3) gives about 9.7% call block probability.

The proposed algorithm can adapt to the call saturated state of network and does not cause high intracell handover rate. The handover rate varies from 34.3% to 44.1%, and the unperformed handover rate varies slightly from 87.5% to 91.4%. For traffic loads over 11 Erlangs, the handover rate decreases, and the unperformed handover rate increases with increasing the traffic load.

This algorithm performs with a short call setup time and at the high traffic load the average time is even slightly shorter. 98% allocated calls are set up on the highest and next highest priority channels. Finally, we suggest that the intracell handover rate should be a factor in evaluation of the performance of an algorithm, because too high intracell handover access will intensively increase the load of switch and cause higher call drop and block probabilities than those we expect.

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