Capacity analysis for mobile cellular systems with Distributed Dynamic Channel Assignment

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Abstract: The comprehensive study of the distributed dynamic channel assignment (DDCA) that had been proposed was primarily based on simulation results. The corresponding theoretical analysis is very complex and seldom. In this paper, the mobile cellular system capacity with DDCA under power control (DDCA/PC) has been investigated. By employing the reuse factor *"phantom"* N_P, a simple close form expression to approximate the call blocking probability has been derived and the system capacity can thus be quickly carried out. The theoretical results resemble closely to that of the simulation [10]. And the system capacity with DDCA/PC substantially increases more than 200% compared to that of the dynamic channel assignment (DCA) or fix channel assignment (FCA) schemes without power control. Furthermore, the system capacity is increased with the larger DDCA/PC gain under stricter power control and expanse of rearrangements. Finally, it shows rather useful to be applied in a practical mobile cellular system.

Keywords---Dynamic channel assignment, Power control, Call blocking probability

Introduction

Dynamic channel assignment has long been proposed as a method to increase capacity in a mobile cellular system. This is achieved through more efficient utilization of the available spectrum, while the minimum C/I for each call in the system is preserved. Dynamic channel assignment schemes in general have higher complexity and require greater regional state information. There is extensive literature on such strategies, and reviews can be found in [5,7,8,9]. The superiority of the dynamic channel assignment (DCA) over the fixed channel assignment (FCA) in terms of system capacity larger had also been reported in literatures [7,8]. This is due to the fact that each cell in DCA may be allocated with any channel according to the traffic loading and electromagnetic compatibility constraints. In practice, the distributed DCA is preferred as the channel allocation process that channels are distributed among base stations, instead of centralized using the Maximum Packing algorithm [7]. The computation and communication among base stations are distributed amongst base stations and thus reduced. Simulation results had shown that the system capacity of employing the distributed DCA with power control (DDCA/PC) has increased substantially more than 200% [3,5,10,11]. Furthermore, the distributed DCA techniques which can be divided into two classes, namely, the Traffic Adaptation DCA (TA-DCA) and the Interference Adaptation DCA (IA-DCA). The TA-DCA scheme performs channel assignments based on the knowledge of the active channels in the neighboring cells and hence it allows the system to manage radio resource according to traffic variations. The IA-DCA scheme performs channel assignment according to the interference in real time. Due to the difficulty in the theoretical analysis for the two schemes, performance evaluation based on simulations had been previously employed and reported in [4,5,9,10]. In this paper, a channel allocation strategy of DDCA/PC scheme combining both the traffic adaptation and the interference adaptation is introduced in Section II. A novel analytical methodology which employs the reuse factor *"phantom"* N_P is proposed to analyze the call blocking probability in Section III. Section IV describes the numerical results and practical application followed by the conclusion in Section V.

Channel allocation strategy and power control

This section describes the system model for the distributed dynamic channel assignment with power control (DDCA/PC) combining both the traffic adaptation and the interference adaptation. Considered a mobile cellular system having regular hexagonal cells, it employs FDMA or TDMA schemes. Assume that there are L orthogonal available channels that are divided into N groups in the system, where N is the system cluster size. Each cell in the cluster has L/N available channels (nominal channel) according to FCA, but it may also allocate the other X available channels ($X=L-L/N$) under the interference constraints if there is no available nominal channel to allocate the arrival calls. The interference includes the co-channel interference only and the adjacent channel interference is neglected. The DDCA/PC scheme employs a cost function to allocate channels followed by the power control in an attempt to reduce the co-channel interference as described in the following subsections. The channel allocation amongst the total available channels is based on that cost function to estimate the interference level so that the minimum one is selected to serve the new arrival call.

The cost functions employed in [8,9,10] were slightly different to each other but the prime constraints remain basically the same. They can be collectively expressed in a general expression:

$$F_k=\sum_{i\in I_c}(C_{k_i}q_{k_i})+q_cC_k \qquad (1)$$

where F_k is the channel interference cost unit for kth channel, I_c denotes the set of co-channel interference cells about cell C, the notation C_{ki} denotes the binary status of I_c which signifies that $C_{ki}=0$ if channel k is available in the cell i and $C_{ki}=1$ if channel k is currently used in the cell i. The weighting factor q_{ki} is used to reflect the distance between the interfering cell i and the cell C. The notation C_k denote the binary status of cell C which signifies that $C_k=1$ when there is no nominal channels in the cell C, otherwise $C_k=0$. The weighting factor q_c is used to reflect the nominal channel occupied grade. The value of q_c is in proportion to that of q_{ki}, normally $q_c=1$ if the nominal channel is being used in cell C. Therefore, any available channel having minimum value of F_k is to be allocated to a new call arising in cell C.

The above available channel selection is followed by power control to reduce the co-channel interference. Assume up-link power control is not considering. Let P^d_{ik} ($P^d_{ik}>0$) denotes *k-th* channel down link effective radiation transmission power from the base station of the cell i and G_{ij} ($G_{ij}>0$) be the radio propagation gain on the path from the base station of cell j to the mobile user in cell i. Suppose that the same channel is used in cell i and reused in cell j with the transmitter power P^d_{jk}, the product $G_{ij}P^d_{jk}$ becomes the amount of co-channel interference to the active user in cell i from cell j. The signal to interference ratio (SIR) for the *k-th* channel in the cell i can thus be generally written as

$$SIR_i=\gamma_i=\frac{G_{ii}P^d{}_{ik}}{\sum_{j\neq i}^{M}G_{ij}P_{jk}{}^d+V_i} \qquad (2)$$

where M is the number of co-channel users in a system and V_i is the Additive White Gaussian Noise (AWGN) of the cell i. If there exists a power vector $P^d=[P_1^d, P^d_2, \ldots P^d_M]$ which is used to represent the respective the power of each co-channel in a system, such that $\gamma_i \geq \gamma$ for $i=1,2,\ldots M$, where γ is the system determined SIR threshold value, the channel k is said achievable and hence can be allocated to cell i. The distributed power control algorithm to search for a locally optimal power for the new call can be thus be written as:

$$P^d_i(k+1)=min\{\ \eta_i(k)P^d_i(k),\ P^d_{max}\ \} \qquad (3)$$

$$\text{where}\quad P^d(0)=P^d_{min},\quad \eta_i(k)=\gamma/\gamma_i(k) \qquad (4)$$

$P^d(0)$ and $P^d(k)$ denote the initial and k-th discrete time transmitted power vector, respectively; P^d_{min} and P^d_{max} are the minimum and maximum transmitted power respectively. This strategy is thus to optimize the overall quality for all on-going calls with the same channel.

Performance analysis

This section presents the analysis for the call blocking probability of DDCA/PC scheme. Consider a cellular mobile system in which the mobile receives signal strength S and total interference strength I, S and I variability depends on both the user and the co-channel user location in the cells if the base station transmission power is fixed. The up-link interference is not considered. It is therefore desirable to allocate channel to arrival call to achieve maximum system capacity as long as the S/I of each individual call is not less than the threshold γ. The DDCA/PC is thus to exercise the power control in order to compromise between the S/I and the system capacity. By adopting the power control into the DDCA which leads to a near-zero variance of *S/I* and ignoring shadow fading, the system capacity C_p for the DDCA/PC can thus be expressed in terms of *S/I* and path loss [3] as

$$C_p = A\ 2^{\frac{-S/I}{1.5\alpha}} \qquad (5)$$

where A is a constant and α is the path loss exponent. Considering a fix channel assignment (FCA) scheme, denotes the *S/I* gain above the threshold γ for the FCA system as $\Delta G_{FCA}=S/I_{FCA}-\gamma$, where S/I_{FCA} is the median value of the signal to interference ratio. Similarly for the DDCA/PC scheme, denotes the *S/I* gain above the threshold γ as $\Delta G_{DCA}=S/I_{DCA}-\gamma$ where S/I_{DCA} is the median value of the signal to interference ratio for the DCA scheme. The resultant DCA gain in term of *S/I* is given by $\Delta G = \Delta G_{FCA} - \Delta G_{DCA}$, where ΔG in unit of dB. The resultant interference adaptation gain of the DDCA/PC relative to that of the FCA is approximately given by

$$g_{IA} = \min\left(N,\ 2^{\frac{\Delta G}{1.5\alpha}} \right) \qquad (6)$$

where g_{IA} is power ratio, N is the number of cells in a cluster. Suppose that there exists a virtue cluster in the DDCA/PC scheme, namely, the new reuse factor *"phantom"* N_P, which is given by

$$N_p = \frac{N}{g_{IA}} \qquad (7)$$

By introducing N_p into the DCCA/PC, the call blocking probability is derived as follows. Let P_i be the probability of having i number of channels occupied. According to the standard *Erlang-B* formula, the stead-state probability distribution P_i is given by

$$P_i = \frac{(N_p\lambda)^i}{i!\,\mu^i} P_0, \qquad 0 < i \leq L \qquad (8)$$

and

$$P_0 = \left(\sum_{k=0}^{L} \frac{(N_p\lambda)^k}{k!\,\mu^k} \right)^{-1} \qquad (9)$$

where L is the total number of channels in system, λ is the call arrival rate in per cell following an independent Possion process and $1/\mu$ is the mean call holding time. Obviously, when total L channels are all occupied in a cluster of size N_p, the call blocking probability is P_L. However, in the DDCA/PC schemes, a new call may be blocked even if the number of channels occupied in its reuse cluster N_P is less than L. Let *b(m)* be the channel occupied probability [2][6] while a channel cannot be assigned purely due to the excessive interference (i.e., S/I < 10*dB*) given m number of channels are occupied in the cluster size of N_p. The *b(m)* for DDCA/PC is thus approximately given by

$$b(m) = \left(\frac{(1-P_L)D}{(g+1)L/N_P} \right)^{\left\lfloor \frac{L-m}{N_P} \right\rfloor} \qquad (10)$$

$$\text{where } D = \frac{\lambda}{\mu}\left(1 + \frac{g}{N_p}\right) \qquad (11)$$

$$g = 2(N_p - 1) \qquad (12)$$

In the above expressions, D is the traffic offered to the dynamic channels. the term $[(1-P_L)D]/[(g+1)L/N_p]$ is the traffic carried by an individual channel per cell and the term $\lfloor (L-m)/N_p \rfloor$ is the approximate average number of unused channels per cell in the cluster of size N_P, where g is the number of co-channel interfering cells for a given cell with the reuse factor *"phantom"* N_p. The operator $\lfloor x \rfloor$ denotes the integer floor part of real number x. By applying the channel occupation probability to equation (10), the call arrival rate λ_m for m channels being occupied in a cluster N_P can be written as

$$\lambda_m = N_P \lambda \{1 - b(m)\} \qquad (13)$$

Then the stead-state probability distribution of the DDCA/PC while j number of channels being occupied in a cluster of N_p is written as

$$P_j = \frac{\prod_{m=0}^{j-1} \lambda_m}{j!\,\mu^j} P_0 \qquad (14)$$

$$\text{where } P_0 = \left(1 + \sum_{k=1}^{L} \frac{\prod_{m=0}^{k-1} \lambda_m}{k!\,\mu^k} \right)^{-1} \qquad (15)$$

Thus the system call blocking probability is equal to

$$P_B = \sum_{j=0}^{L} b(j) P_j \qquad (16)$$

where $b(j)$ and P_j are given in equation (10) and (14), respectively.

Numerical results and practical application

This section presents the performance of the DDCA/PC, FCA and the ordered-DCA (ODCA)[8] schemes. For the sake of comparison, we assume N=7, L=70 and $1/\mu$ =120sec. As shown in figure 1 when λ=0.15, the call blocking probabilities for the DDCA/PC (ΔG=10dB), the FCA and the order-DCA schemes are respectively given by 0.011, 0.49 and 0.50. Observe that the FCA is superior to ordered-DCA under high traffic load. For light to medium traffic load, the ordered-DCA becomes superior instead. Moreover, the DDCA/PC has greatly reduced the blocking probability by more than 300% compared to that of ODCA and FCA. Note that our theoretical results resemble to that of the simulation results obtained from [10]. For instance, the difference between the two results is no more than 8% and 6% for light traffic and high traffic, respectively. Figure 2 depicts the performance of the DDCA/PC algorithms having different values of ΔG. The blocking probabilities P_B decreases with increasing ΔG. An increase of $2dB$ in ΔG, P_B reduces by more than 300% and 100% for light traffic and high traffic level, respectively. Thus, the respective system capacity has therefore increased. Actually, the expanding ΔG adapts larger S/I variance by power control to increase the system capacity.

In practical application, for example, a real cellular system has 70 available channels, the mean call holding time is 180s, assume all cell size is same and the call blocking probability is less than 5%, the S/I varies from minimum 10dB to maximum 33dB. The system capacity with DDCA/PC scheme can be simple proposed to increase more than 70% compared to FCA scheme according to the analysis result in this paper.

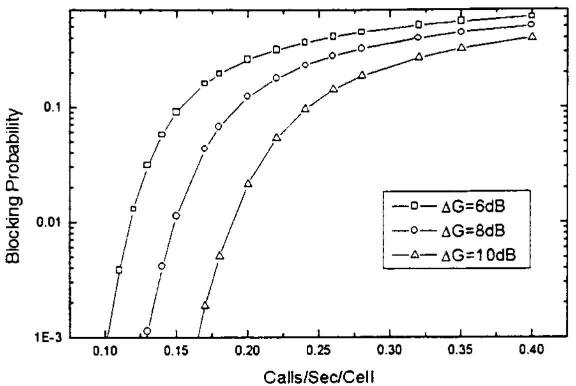

Fig.1 The call blocking probability of DDCA/PC having different values of ΔG

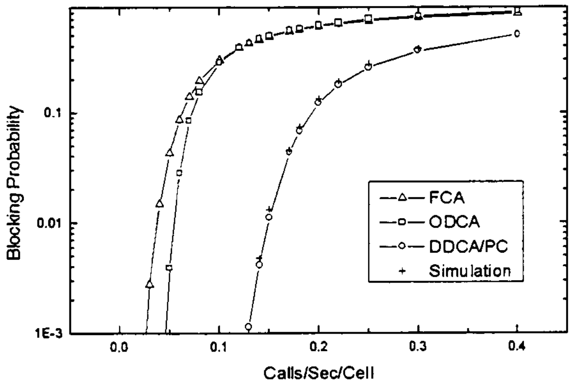

Fig.2 The call blocking probability of FCA, ODCA and DDCA/PC schemes

Conclusion

As a close form expression for the blocking probabilities of the distributed DCA schemes is formidable, many of the previous research works were based on simulation. This paper presents a close for expression to approximate the call blocking probability for the DDCA/PC algorithms using *"phantom"* N_P. It has been shown that the analytical results resemble to that of simulation [10] having the difference of less than 8%. The analytical results had also shown that the DDCA/PC scheme greatly reduces the call blocking probability compared with FCA and ODCA. An increase of 2dB in ΔG would reduce P_B more than 100%. Furthermore, the result is useful in practical application to carry out a cellular system capacity with DDCA/PC.

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