Performance Analysis of Dynamic Channel Assignment for Cellular Mobile Radio Systems

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Abstract

The study of the dynamic channel assignment (DCA) that had been widely carried out was primarily based on simulation results. The corresponding theoretical analysis is seldom. In this paper, the performance of distributed dynamic channel assignment with power control (DDCA/PC) combining both the traffic adaptation and the interference adaptation has been investigated. By employing the reuse factor "*phantom*" N_P, a close form expression to approximate the call blocking probability for the DDCA/PC has been derived. The theoretical results resemble closely to that of the simulation [10]. It has also been shown that the call blocking probability of the DDCA/PC is substantially reduced by more than 350% and 300% compared to that of the DCA and fix channel assignment (FCA) schemes, respectively.

Index Terms---Dynamic Channel Assignment, Power control, Cellular mobile radio systems

I. INTRODUCTION

The demand in mobile telephone services has seemingly ever increased over the last two decades. Due to the limited frequency spectrum, an efficient channel assignment scheme becomes an important issue in cellular network planning. Both the fixed channel and dynamic channel assignment schemes had been widely studied [5,7,8,9]. The superiority of the dynamic channel assignment (DCA) over the fixed channel assignment in terms of system capacity larger than 30% had been reported in literatures [5,7,8] under the light to medium traffic load. 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 is 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 [3,5,10,11] that the system capacity for a system employing the distributed DCA equipped with the power has increased substantially by 300%. This paper investigates the distributed DCA techniques which can be further 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, the distributed dynamic channel assignment with power control (DDCA/PC) combining both the traffic adaptation and the interference adaptation are introduced in Section II. A novel analytical methodology which employs the reuse factor "*phantom*" N_P is proposed to analyze the blocking probability in Section III. Section IV describes the analytical results followed by the conclusion in Section V.

II. SYSTEM MODEL

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. The system model considered is based on a mobile radio cellular system having regular hexagonal cells. It employs FDMA or TDMA schemes. Assume that there are L orthogonal available channels in the system which are divided into L/N groups, where N is the system cluster size. Each cell in the cluster has L/N available channels (nominal channels) for the fix channel assignment to allocate channels, 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 in the call arising cell. The interference includes the co-channel interference only and the adjacent channel interference is neglected. The DDCA/PC scheme is therefore to employ 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 the cost function which calculates the interference level so that the minimum one is selected to serve the new arrival call.

A. Cost Function

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:

$$F_k = \sum_{i \in I_c} (C_{ki} q_{ki}) + q_c C_k \qquad (1)$$

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.

B. Power Control

The power control is also employed into the channel allocation schemes (DDCA/PC) as follows. 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 ERP 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:

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

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

$P^d(0)$ 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. The power control is thus to optimize the overall quality for all on-going calls with the same channel. Furthermore, the up-link power control which is not within the scope of this discourse can also be derived in a similar manner.

III. PERFORMANCE ANALYSIS

This section presents the analysis for the call blocking probability of DDCA/PC scheme. Consider a cellular system in which both the mobile received signal strength S and the mobile received total interference strength I depend on both the user location within the cell and the co-channel users of the other cells. The uplink interference is not considered. It is therefore desirable to allocate channel to call to achieve its 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 all the total L channels are occupied in a cluster of size N_p, the call blocking probability is given by 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

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

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, the notation 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, 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, the notation g is the number of co-channel interfering cells for a given cell with the reuse factor "*phantom*" N_p and the operator $\lfloor x \rfloor$ denotes the integer part of real number x. By applying the channel occupation probability to equation (10), the call arrival rate λ_m given m channels being occupied in a cluster N_P is written as

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

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

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

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.

IV. NUMERICAL RESULTS

This section presents the performance of the DDCA/PC, FCA and the ordered-DCA (ODCA) channel assignment schemes. For the sake of comparison between the three schemes, 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 when the traffic load is high (i.e. $\lambda \geq 0.2$ in Fig.1). For light to medium traffic load level (i.e. λ<*0.2* in Fig.1), the ordered-DCA becomes superior instead. Moreover, the DDCA/PC has greatly increased the system capacity and reduced the blocking probability by more than 350% and 300% compared to that of the ODCA and the FCA, respectively. 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 2*dB* in ΔG, P_B reduces by more than 300% and 100% for light traffic (i.e. λ<*0.2* in Fig.2) and high traffic (i.e. $\lambda \geq 0.2$ in Fig.2), respectively. The respective system capacity has therefore increased by about 70% and 50%. The increase in ΔG adapts larger *S/I* variance by power control to increase the system capacity.

V. 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 reduces the blocking probability by more than 300% and 350% compared to that of FCA and ODCA schemes, respectively. An increase of 2dB in ΔG would reduce P_B by more than 300% and 100% for light traffic and high traffic, respectively.

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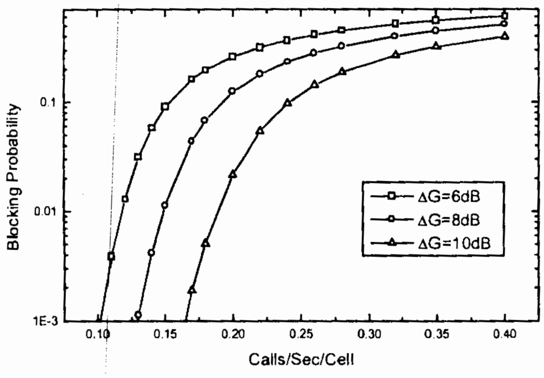

Fig.1 The call blocking probability of DDCA/PC schemes having different values of ΔG

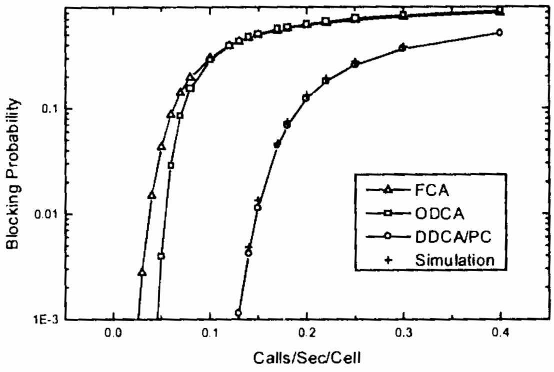

Fig.2 The call blocking probability of FCA, ODCA and DDCA/PC schemes