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Hybrid heuristic-waterfilling game theory approach in MC-CDMA resource allocation☆

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ABSTRACT

This paper discusses the power allocation with fixed rate constraint problem in multi-carrier code division multiple access (MC-CDMA) networks, that has been solved through game theoretic perspective by the use of an iterative water-filling algorithm (IWFA). The problem is analyzed under various interference density configurations, and its reliability is studied in terms of solution existence and uniqueness. Moreover, numerical results reveal the approach shortcoming, thus a new method combining swarm intelligence and IWFA is proposed to make practicable the use of game theoretic approaches in realistic MC-CDMA systems scenarios. The contribution of this paper is twofold: (i) provide a complete analysis for the existence and uniqueness of the game solution, from simple to more realist and complex interference scenarios; (ii) propose a hybrid power allocation optimization method combining swarm intelligence, game theory and IWFA. To corroborate the effectiveness of the proposed method, an outage probability analysis in realistic interference scenarios, and a complexity comparison with the classical IWFA are presented.

1. Introduction

In the last years the telecommunication scenario has been passing through a huge increase in traffic demand due to the arrival of new devices and services. In this context, the multiple access networks represent an important solution, once these systems can admit more users and, at the same time, achieve a higher throughput than other technologies. Thus, a specific multiple access system draws the attention of many researchers nowadays: the MC-CDMA networks. Even with all these avails, since all users transmit at the same time and in the same spectrum a resource allocation scheme must be adopted in order to guarantee acceptable quality of service (QoS) requirements, associated with minimum rates, maximum allowed delay, maximum permitted bit error rate (BER) and so forth.

1.1. Motivation

The study of resource allocation problems in wireless networks has been discussed for many years due to its impacts in company profits and user satisfaction. Additionally, current technologies do not provide enough bandwidth at low operational costs for corporations which also affects their customers. So, a practical resource allocation scheme is desirable in order to save power,[1] increase the throughput and guarantee the QoS.

1.2. Related work

Several studies have been conducted in recent years in order to find good resource allocation algorithms. Within this context, some works may be highlighted [1–9].

The distributed power control algorithm (DPCA) proposed in [1] is considered the base of many well known DPCAs. In [2] a multi-objective resource allocation scheme is presented. The

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[1] Saving power may increase battery lifetime.

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algorithm considers three different non-linear parameters that weight the procedure goals: minimize the power, guarantee the QoS (in terms of target rate) and maximize the rate. In addition, a DPCA for single-rate [3] and multi-rate networks [4] inspired on Verhulst equilibrium analytical-iterative model is proposed in order to solve the power allocation with rate constraints problem in DS/CDMA networks.

On the other hand, heuristic approach based on swarm intelligence was applied to solve the power allocation with rate constraints [5] and the rate maximization problem [6]. Besides, the total network power minimization problem subject to multi-class information rate constraints, as well as the problem of throughput maximization constrained to power limitation was analyzed in [7] applying swarm intelligence. The motivation to use heuristic search algorithms is due to the nature of the NP complexity posed by the wireless network optimization problems. The challenge is to obtain suitable performances in solving those hard complexity problem in a polynomial time.

Previous results indicated that the application of heuristic search algorithm in several wireless optimization problems have been achieved excellent performance-complexity tradeoffs, particularly the use of genetic algorithm, evolutionary program, particle swarm optimization (PSO), and local search algorithm. Concerning the resource allocation issue, there are several challenging single- or multi-objective optimization problems associated, such as the total network power minimization subject to multi-class information rate constraints, as well as the throughput maximization while minimizing the total transmitted power. Multi-rate users associated with different types of traffic can be aggregated to distinct classes of users, with the assurance of minimum target rate allocation per user and quality of service (QoS). In order to achieve promising performance-complexity tradeoffs, both continuous or discrete PSO search algorithms have been successfully employed in the resource allocation problems [7].

A game theoretic approach for power control with rate constraints in Gaussian parallel interference channels using water-filling algorithm is proposed in [8], while in [9] a multi-linear fractional programming approach is used to solve the weighted throughput maximization problem in multiple access systems. However, under strong interference density configurations, iterative water-filling algorithm (IWFA) is unable to offer promising solutions to power allocation with fixed rate constraint in multi-carrier code division multiple access (MC-CDMA) networks. Hence, in this work the existence and uniqueness of the solution are studied and shown by numerical results that a new method combining swarm intelligence and IWFA is more promising and suitable for realistic MC-CDMA scenarios.

1.3. Organization

This paper is organized as follows: Section 2 presents the system model and description; the game theoretic approach is presented in Section 3. Section 3.3 discusses the iterative water-filling algorithm (IWFA); moreover, in Section 4 the scenarios are characterized and further the game theoretic plus IWFA approach are applied in orde to solve the power-rate allocation problem. Finally, the proposed hybrid approach is discussed in Section 5 and conclusions in Section 6.

2. System description

In multiple access networks an important QoS measure is the signal to interference plus noise ratio (SINR) since all users transmit over the same channel at the same time causing what is known as multiple access interference (MAI), which is responsible for the soft capacity of CDMA systems. The spectrum may be divided in N uncorrelated CDMA sub-channels such that each one is a flat channel, therefore, more appropriate to high transmission rates.

In MC-CDMA systems the SINR at the i th user k th sub-carrier may be computed as follows [9]:

$$\delta_i(k) = \frac{p_i(k)|g_{ii}(k)|^2}{\rho \sum_{j \neq i} p_j(k)|g_{ij}(k)|^2 + \sigma_i^2(k)} \tag{1}$$

where p is the allocated power, $|g|^2$ is the channel gain, ρ is proportional to the average channel cross-correlation among all users, and σ^2 is the power noise at the respective users (i) and sub-carriers (k).

The power allocation with rate constrains problem is a well known telecommunications issue of non-convex nature. A generalized statement of this problem for MC-CDMA systems follows:

$$\begin{aligned} \min \quad & \sum_{i=1}^{U}\sum_{k=1}^{N} p_i(k) \\ \text{s.t.} \quad & \sum_{k=1}^{N} r_i(k) \geq r_i^* \\ & 0 \leq p_i(k) \leq p_{\max} \end{aligned} \tag{2}$$

where U is a total number of users sharing the channel, N is the number of sub-carriers available, and r_i^* is the target information rate at the i th user.

3. Game theory approach

A simple game $\mathcal{G}$ can be easily defined as a tuple composed by the set of players $\mathcal{U}$, strategies $\mathcal{P}$, and utilities $\mathcal{F}$. Mathematically:

$$\mathcal{G} = \{\mathcal{U}, \mathcal{P}, \mathcal{F}\} \tag{3}$$

In multiple access networks resource allocation games, the players would be the active users in the system, $\mathcal{U}$ in (3), the strategies would be the resources allocated to each one, e.g. the power each user utilizes to transmit, $\mathcal{P}$ in (3), and the utilities the payoff functions, $\mathcal{F}$ in (3), that evaluate the strategies chosen.

Games may be played either with or without cooperation among users. Herein a non-cooperative scenario is considered. Hence, as it is well known, non-cooperative games may be solved finding the Nash equilibrium(s) (NE) of the problem [8,10]. A NE is a set of strategies where any unilateral change in the user strategy will not increase the users' utility without decreasing others payoffs. Therefore, problem (2) may be rewritten as follows [10]:

$$\begin{aligned} \min \quad & \sum_{i=1}^{U}\sum_{k=1}^{N} p_i(k) \\ \text{s.t.} \quad & r_i(\mathbf{p}_i) \in R_i^* \\ & \mathbf{p}_i \in \mathcal{P} \end{aligned} \tag{4}$$

where R_i^* is the set of possible achievable information rates, $\mathcal{P}$ is the set of possible strategies (allocated powers) at each sub-carrier and $r_i(\mathbf{p}_i)$ is the rate function given the set of power through all sub-carriers, defined as:

$$r_i(\mathbf{p}_i) = \sum_{k=1}^{N} \log[1 + \delta_i(k)] \tag{5}$$

In multiple access scenarios it is important to observe that each users' power choice interferes in all other user performance. In this