Information Sciences 293 (2015) 1–10

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Proportional fair resource allocation based on hybrid ant colony optimization for slow adaptive OFDMA system

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ARTICLE INFO

Article history:
Received 6 March 2014
Received in revised form 18 August 2014
Accepted 3 September 2014
Available online 28 September 2014

Keywords:
Chance-constrained optimization
OFDMA
Proportional fair resource allocation
Hybrid ant colony optimization

ABSTRACT

Proportional fair resource allocation plays a critical role to enhance the performance of slow adaptive orthogonal frequency division multiple access (OFDMA) system. In slow adaptive OFDMA system, the subcarrier allocation is updated at the beginning of every time window and the channel gain of users at the time of the subcarrier allocation could not be known precisely. This leads to the challenge for designing the resource allocation algorithm for slow adaptive OFDMA system. In this work, we formulate a proportional fair resource allocation problem based on chance-constrained programming for slow adaptive OFDMA system which maximizes the average sum-rate in an adaptive time window and guarantees the Jain fair index (JFI) requirement with the target probability. In order to solve the chance-constrained resource allocation problem, we propose hybrid ant colony optimization (HACO) which combines ant colony optimization (ACO) and support vector machine (SVM). Simulation results demonstrate that HACO not only yields higher average sum-rate, but also guarantees the chance-constrained condition very well compared with other algorithm.

1. Introduction

Due to the robustness of resisting the frequency-selective multipath channel, orthogonal frequency division multiplexing (OFDM) has been widely recognized as one of the key techniques for the next wireless network [1]. For example, it has become the primary physical layer architecture in IEEE 802.11 n/ac, HIPERLAN/2 and the 3GPP long-term evolution. The basic concept of OFDM is that the total rate is divided by the number of subcarriers and data is transmitted on a number of different subcarriers in parallel [2].

To make efficient use of orthogonal frequency division multiple access (OFDMA) system resource, fast adaptive resource allocation problems have been studied widely for multiuser OFDMA system [3–8]. In [3], Seo proposes an adaptive power allocation algorithm with cumulative distribution function based scheduling for multiuser OFDMA system. However, [3] only considers the power allocation of multiuser OFDMA system. In order to utilize the frequency spectrum resource of multiuser OFDMA system efficiently, Shen and Sharma propose two joint subcarrier and power resource allocation algorithms from the perspective of guaranteeing user's fairness [4,5] and Wang proposes a joint subcarrier and power allocation algorithm from the perspective of saving energy [6]. However, [3–6] study the centralized resource allocation algorithms which

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http://dx.doi.org/10.1016/j.ins.2014.09.028
0020-0255/

generate the excessive control overhead, thence it is necessary to develop the distributed resource allocation algorithms for multiuser OFDMA system. In [7], Abdelnasser proposes a semi-distributed resource allocation algorithm based on joint clustering and resource allocation in a two-tier multiuser OFDMA system. In [8], Jeon proposes a distributed resource allocation algorithm for multiuser OFDMA downlink system.

The resource allocation algorithms in [3–8] focus on the resource allocation problems of the physical layer and they do not consider the influence of the upper protocol to resource allocation. Therefore, many scientists begin to investigate the cross-layer resource allocation problems for multiuser OFDMA system [9–13]. In [9], Song establishes a theoretical framework for cross-layer optimization of multiuser OFDMA system and proposes a practical resource allocation algorithm. However, the resource allocation algorithm in [9] does not consider the user's fairness, Therefore, Cheng proposes a cross-layer resource allocation algorithm with proportional fair constraint for multiuser OFDMA system [10] and Escudero-Garzas presents a cross-layer resource allocation algorithm for multiuser OFDMA downlink system with fairness control among the users [11]. In order to reduce the control overhead of the cross-layer resource allocation algorithms, [12,13] studies the distributed cross-layer resource allocation problems for multiuser OFDMA system. In [12], Wang proposes a distributed cross-layer resource allocation algorithm to achieve multi-channel allocation based on attachment learning for multiuser OFDMA system. In [13], Le considers the joint resource allocation and admission control problem for multiuser OFDMA system and proposes a distributed cross-layer power resource algorithm utilizing the game theory.

In order to improve the performance of multiuser OFDMA system further, researchers begin to study the resource allocation problems for relay-based multiuser OFDMA system [14–17]. In [14], Joung proposes a power efficient resource allocation algorithm with the homogeneous traffic for relay-based multiuser OFDMA system [14]. Tailored for the heterogeneous services, Shamsul proposes an joint optimal relay selection, power allocation and subcarrier allocation algorithm for relay-based multiuser OFDMA system [15]. [14,15] assume the perfect channel state information (CSI) for relay-based multiuser OFDMA system, but this assumption is impossible in the practice. Therefore, Chang investigates the resource allocation problem based on the imperfect CSI for relay-based multiuser OFDMA system [16] and Mokari proposes a resource allocation algorithm based on quantized CSI for relay-based cognitive OFDMA system [17].

In fast adaptive OFDMA system, subcarrier allocation must be performed once the instantaneous CSI changes [3–17]. This will lead to the huge feedback overhead and control overhead. In order to solve this problem, slow adaptive OFDMA system is proposed [18]. In [18], Li proposes a resource allocation algorithm utilizing the Bernstein approximation method which maximizes the long-term average throughput while satisfying the short-term probabilistic data rate requirements. However, [18] does not consider the chance-constrained resource allocation problem based on the proportional fair traffic service. Therefore, this work tries to solve the proportional fair resource allocation problem with the chance-constrained programming which balances the capacity and the fairness for slow adaptive OFDMA system. In addition, we propose hybrid ant colony optimization (HACO) algorithm to solve it instead of adopting the Bernstein approximation method in [18]. The main contributions of this work are as following:

- Formulate a new proportional fair resource allocation problem based on the chance-constrained programming for slow adaptive OFDMA system.
- Utilize the stochastic simulation method and support vector machine (SVM) to compute the uncertain function which is transformed by the probabilistic Jain fair index (JFI) constraint condition.
- Combine SVM and ant colony optimization (ACO) to develop HACO which solves the proportional fair resource allocation problem for slow adaptive OFDMA system.

This work is organized as following. Section 2 introduces the system model and presents the proportional fair resource allocation problem based on chance-constrained programming. In Section 3, HACO is developed and the computational complexity is analyzed in Section 4. Simulation result is presented in Section 5 and conclusion is drawn in Section 6.

2. System model and optimization problem formulation

2.1. System model

We consider slow adaptive OFDMA system with M users and the whole available bandwidth W is divided into K subcarriers. Moreover, $\mathbf{M} = \{1,2,\ldots,M\}$ and $\mathbf{K} = \{1,2,\ldots,K\}$ represent the user set and the subcarrier set, respectively. As is similar with [18], a time window is defined and the duration T of a time window is larger than that of fast fading fluctuation so that the channel fading process over the time window is ergodic and smaller than that of the large-scale channel variation so that path-loss and shadowing are considered to be fixed in every time window. In this work, the subcarrier allocation algorithm is performed at the beginning of every time window and we adopt the statistical CSI between the transmitter of base station (BS) and the receiver of users because the CSI at the stage of the subcarrier allocation is uncertain. In order to capture the uncertainty of CSI, we assume the instantaneous channel coefficients $h_{m,k}(t)$ of user m on subcarrier k at time t is the complex Gaussian random variable and the channel gain $g_{m,k}(t)$ of user m on subcarrier k at time t could be defined by (1).

$$g_{m,k}(t) = |h_{m,k}(t)|^2 \tag{1}$$