A QoE-Oriented Strategy for OFDMA Radio Resource Allocation based on Min-MOS Maximization

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Abstract

A balanced strategy for OFDMA radio resource allocation based on game theory concepts is presented. Its main novelty with respect to state-of-the-art methods is that resource allocation is based on application-oriented Mean Opinion Score (MOS), rather than the aggregate system data rate. Thus, users' data flows cooperate in a proactive way in order to jointly maximize the Quality of Experience (QoE). Experimental results show that the MOS achievable by the proposed resource allocation strategy is higher than the one provided by uncoordinated strategies based on water-filling and cooperative strategies based on pure data rate maximization.

Index terms: ***OFDMA, Radio Resource Allocation, Game Theory, QoS measurements, QoE***

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I. INTRODUCTION

The problem of optimal allocation of power and subcarrier resources in OFDM and OFDMA systems has been widely dealt with in the literature [1]. The tradeoff between efficiency (i.e.: maximum attainable data rate) and fairness is one of the most challenging aspects of OFDMA. State-of-the-art solutions are suboptimal; indeed: (i) efficiency tends to privilege users with good channel conditions, who are generally closer to the base-station; (ii) fairness is based on criteria like max-min that do not consider the notion that different users might have different requirements. In some recent papers, solutions to this problem have been proposed based on "negotiation" strategies inspired by everyday life. The core idea is to model Radio Resource Management (RRM) as a marketplace where transmitting users can exchange commodities (i.e.: power and/or subcarriers) and negotiate transactions, so that needs can be satisfied through bargaining [2]. This motivates the application of game theoretic ideas to the OFDMA RRM problem. A non-cooperative resource competition game is proposed in [3] in contrast to the cooperative approach of [2].

In this letter, we propose a novel approach for OFDMA RRM that intrinsically aims at optimizing the fairness in terms of satisfaction of heterogeneous users' requirements (voice, video, and data). In particular, we consider a utility function aimed at the maximization of the minimum Mean Opinion Score (MOS) experienced by the users. Saul and Auer already demonstrated the advantages of using MOS instead of bit-rate and Bit-Error Rate (*BER*) to optimize performance between the application and MAC layers [4]. The goal is to achieve the best possible QoE in terms of the minimum estimated MOS. In this way, the RRM should increase fairness in order to allow users to be satisfied as much as possible with respect to their actual QoE expectations. The proposed approach has been inspired by game theory, whose key focus is the study of how to achieve satisfactory equilibria through market-like resource exchanges.

II. OFDMA SYSTEM MODEL

The OFDMA system shares a fixed bandwidth B spanned around a transmission frequency f_c and shared among K users. The available bandwidth is partitioned into N subcarriers, each one of bandwidth B/N [Hz]. As is customary in the literature (see e.g. [1]) the channel is assumed flat over each subcarrier.

The usual objective of RRM in OFDMA systems is to maximize the system data rate with a constraint on the bit-error-rate (BER), i.e.:

$$\begin{cases} \max_{c_{n,k},p_{n,k}} \dfrac{B}{N}\displaystyle\sum_{n=0}^{N-1}\sum_{k=1}^{K} c_{n,k}\log_2\left(1+\dfrac{\alpha_{gap}p_{n,k}g_{n,k}}{\sigma^2}\right) \\ \displaystyle\sum_{k=1}^{K} c_{n,k}=1\ \forall n, \quad \sum_{n=0}^{N-1} c_{n,k}p_{n,k}\le P_{tot}\quad \forall k \end{cases} \tag{1}$$

where $p_{n,k}$ is the power allocated to user k on subcarrier n, $g_{n,k}$ is the channel power gain, σ^2 is the Gaussian noise variance, $c_{n,k}\in\{0,1\}$ is the subcarrier allocation indicator, and α_{gap} is the signal-to-noise ratio gap, expressed as a function of the target *BER*. In the presence of constraints on the total available power, the resource allocation strategy maximizing the total system throughput is *water-filling*. Water-filling tends to maximize power allocation on those subcarriers having the highest signal-to-noise ratio (*SNR*), while penalizing those subcarriers having lower *SNR* by minimizing power allocation to them, requiring, “fairness” strategies in radio resource allocation to be considered and (for an overview see [1]).

III. COOPERATIVE OFDMA RRM ALGORITHM BASED ON QOE

The key concept underlying the proposed approach is to define a cooperative game representing the process of resource allocation to data flows in a mixed traffic configuration. The utility function of the cooperative game is expressed in terms of Mean Opinion Score (MOS) estimated for each data flow. MOS is expressed by a real number ranging from 1 to 4.5, with a satisfaction threshold commonly set to 4.

We consider three different classes of data flows: "video streamers", "audio streamers" and "best effort", the latter indicating users requiring data transfer. For audio and best-effort applications, a suitable logarithmic model for MOS is the following [4]:

$$MOS_{a,BE} = a\log\left\{bR_{a,BE}\left(1 - PEP_{a,BE}\right)\right\} \quad (2)$$

$R_{a,BE}$ being the transmission rate achieved by audio and/or best-effort users and $PEP_{a,BE}$ the target packet-error-probability, defined on the basis of standard user profiles (target PEP is directly linked with target BER).

The constants a and b are computed by fixing the MOS at a given rate value $R_{a,BE}$ and $PEP_{a,BE}$=0. It is shown in [5] that the MOS for audio streamers is closely related to other quality parameters accepted by the ITU for voice applications like the Rating (R) factor. For video streaming, the following MOS model is used [4] ($PSNR_{vd}$ is the PSNR achieved by video users):

$$\begin{cases} 1 & PSNR_{vd} \le PSNR_1 \\ d\log\left(PSNR_{vd}\right) + e & PSNR_1 < PSNR_{vd} < PSNR_{4.5} \\ 4.5 & PSNR_{vd} \ge PSNR_{4.5} \end{cases} \quad (3)$$

The constants d and e are derived according to threshold values of the $PSNR$. In particular, $PSNR_1$ and $PSNR_{4.5}$ are the threshold values needed to achieve MOS equal to 1 and 4.5 respectively. $PSNR_{vd}$ is related to the data-rate of the video stream R_{vd}, using the IP-based streaming model proposed in [6] (the parameters u, v, and w characterize the specific video sequence):

$$PSNR_{vd} = u + v\sqrt{R_{vd}/w}\left(1 - w/R_{vd}\right) \quad (4)$$

In general, MOS increases with data-rate, but not linearly – since it is not always true that an increase of the data rate brings a proportional increase in terms of MOS. Moreover, as shown in (1), the achievable rate is linked to the target BER and to the channel conditions, which are specific for each user. In the proposed RRM approach, the overall target of the game is the identification of the resource allocation that enables the maximization of the minimum expected MOS, and thus the corresponding QoE. Players are represented by data flows with specific resource requirements. In order to enable negotiation of resources, the game is organized like a "championship" in several rounds, with challenges, or negotiations between pairs of users. The RRM algorithm is sketched in Tab.1.

The user-pair negotiation is similar to the one proposed in [2], but using a different utility function. On the other hand, the multi-user negotiation methodology is different. In [2], random coalitions of user pairs and the Hungarian algorithm for optimal coalition selection are used. The first methodology is clearly sub-optimal, while the second one is computationally expensive. Moreover, the challenge is interrupted when the minimum MOS, computed for all users, exceeds the satisfaction threshold, saving computational resources.

The complexity of the algorithm is $O(KNlogN)$. On the other hand, exhaustive search, water-filling and the coalition-based game-theoretical approach of [2] would lead to $O(K^N)$, $O(KN)$, and $O(K^2Nlog\,N+K^4)$ respectively.

The proposed scheme, rather than maximizing the overall bit rate subject to fairness constraints, provides a paradigm shift to a user-centric approach where a more appropriate allocation is performed based on the specific requirements of each data flow in terms of QoE. Several related papers dealing with RRM in multi-user transmission systems able to support heterogeneous traffic flows have recently been published in the literature ([7-9]). They generally address the problem by implementing RRM and scheduling algorithms (or a combination between RRM and scheduling [9]) to optimize resource allocation and traffic distribution as a function of certain network parameters. These parameters are typically related to the actual QoS requests and traffic typology (e.g. average data rate, maximum allowable delay, priority profiles, real-time/not real-time, QoS-guaranteed/best effort, etc.). Our approach is different in the sense that it is based on a strategy aimed at balancing the QoE in terms of a qualitative indicator (i.e. the MOS). Indeed, we believe that the maximization of the minimum MOS achieved by the user population enables a quantitatively unambiguous evaluation of the QoE and system fairness. Moreover, it must be clarified that this work is based on a connection-oriented strategy, since resources are allocated to flows and not single packets.

IV. EXPERIMENTAL RESULTS

Validation is performed through simulations in the MATLAB-SIMULINK environment. K=30 users of mixed typology (10 video streamers, 10 audio streamers and 10 best-effort users) share N=256 subcarriers distributed over B=4MHz bandwidth. User profiles in terms of data-rates, *BER* and *PEP* are derived according to [10]. The multipath intensity profiles of the frequency-selective channel models of type SUI-5 (maximum delay spread, Rayleigh fading) and SUI-2 (low delay spread, Rice fading) are considered in our simulations as relevant examples related to actual WiMAX applications [11]. In this work, the channel is always assumed time-invariant. The Doppler effect is neglected. Fig.1 and Fig.2 show the minimum MOS and the overall bit-rate vs. *SNR* obtained by the different RRM algorithms assessed in this paper, simulating the delay profiles of SUI-5 and SUI-2 channel models respectively. In particular, the following algorithms have been compared: a) the proposed QoE-driven cooperative approach, b) a cooperative approach based on rate maximization, similar to that one shown in [2], adopting the challenge negotiation mechanism shown in Sect. III, and c) an OFDM-FDMA approach with static allocation of users' subcarriers and waterfilling inside each user's subcarrier group with fairness constraints [12]. Results shown in Fig.1 and 2 have been obtained by averaging several hundred simulations characterized by different channel and noise realizations. It is easy to see that the improvement of the MOS index achieved by the proposed RRM strategy is significant, both with respect to the OFDM-FDMA strategy and to cooperative rate-maximization. It is interesting to note that the maximization of the MOS index is not directly related to the maximization of the overall system data-rate. This happens since max-rate strategies merely maximize the aggregated data rate, without considering the impact on the effective QoE. The impact of channel frequency selectivity on RRM performance is more evident at lowest *SNRs*. In such cases, the minimum MOS achieved by the proposed algorithm is decreased when the SUI-5 delay profile is adopted. However, it still remains superior to the corresponding values achieved by OFDM-FDMA and cooperative max-rate RRM, in particular for the SUI-2 channel profile.

V. CONCLUSIONS

This letter proposes a cooperative RRM strategy with the objective of maximizing QoE of OFDMA users to achieve a mutual benefit. The proposed approach, explicitly addressing users' perceived quality, ensures highest balance between efficiency and fairness, resulting in a QoE increase with respect to available RRM strategies.

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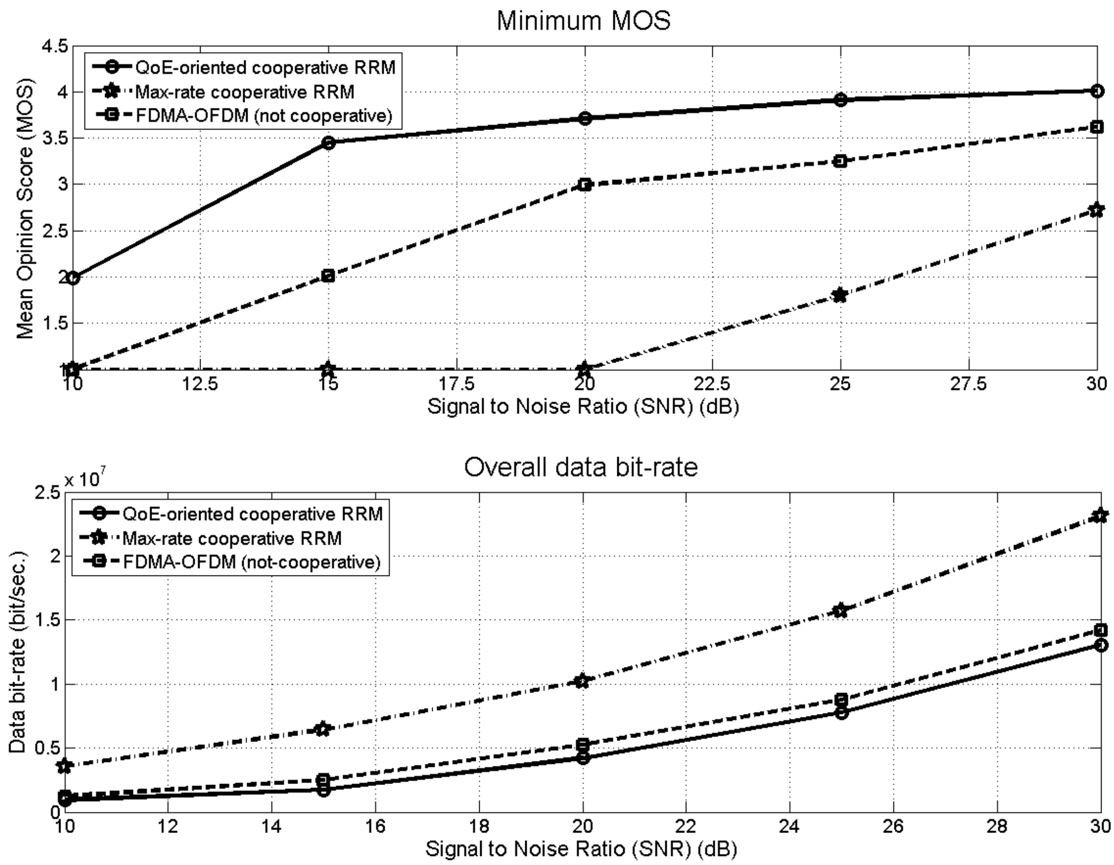

Figure 1. Minimum-MOS and overall data bit-rate achieved by the different RRM strategies, K=30 users (mixed typology), SUI-5 channel

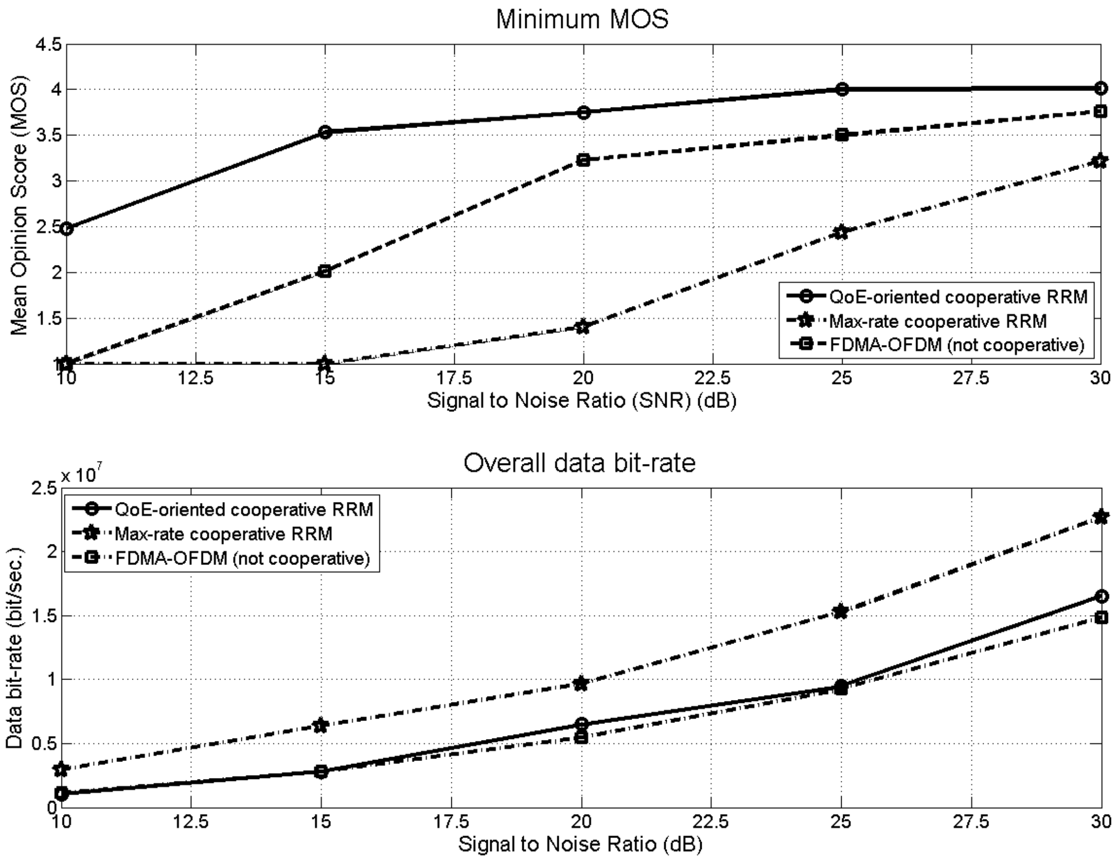

Figure 2. Minimum-MOS and overall data bit-rate achieved by the different RRM strategies, K=30 users (mixed typology), SUI-2 channel

1.	**ALGORITHM INITIALIZATION**
•	The subcarrier set is partitioned into groups, each one consisting of N_0=*floor(N/K)* subcarriers. These subcarrier groups are randomly assigned to transmitting users;
•	Water-filling is performed over the assigned subcarriers;
•	The utility function *U* (minimum MOS) is computed using power allocation matrix $P_0 \triangleq [p_{n,k}(0)]$ and subcarrier allocation matrix $C_0 \triangleq [c_{n,k}(0)]$ obtained after the initial water-filling allocation. If *U*>4, the algorithm stops, otherwise go to step 2)
2.	**COMPETITION AMONG USER PAIRS WITH NEGOTIATION**
•	The subcarrier sets attributed to a user pair (k_1,k_2) are grouped together in a unique set of cardinality $N(k_1,k_2)$;
•	The related subcarriers are sorted according to $g_{n,k1}/g_{n,k2}$ from the largest to the smallest one;
•	A loop is performed for all the subcarriers attributed to the user pair (k_1,k_2): water-fill for user k_1 using subcarrier indexes *0* to *n*, water-fill for user k_2 using subcarrier indexes *n*+1 to $N(k_1,k_2)$–1.
•	The utility function $U(k_1,k_2)= min(MOS (k_1),MOS (k_2))$ is computed for each subcarrier index *n*;
•	The challenge (k_1,k_2) ends. The index *n* maximizing $U(k_1,k_2)$ is returned. The bit power allocation matrix *P* and the bit allocation matrix *C* are recalculated after the challenge: P_1 -> $P(k_1,k_2)$ and C_1 ->$C (k_1,k_2)$.
3.	**ALGORITHM TEST AND STOP CRITERION**
•	The utility function *U* is computed for all users by using P_1 and C_1 matrices computed in Step 2;
•	If *U*>4, the algorithm stops. Otherwise, another user pair competition is initiated (go to Step 2);
•	The algorithm stops when: a) *U*>4, or: b) the last of the possible *K(K-1)* user pair competitions ends.

Table 1. The proposed QoE-oriented RRM algorithm for OFDMA