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QoS BASED RADIO RESOURCE ALLOCATION AND SCHEDULING WITH DIFFERENT USER DATA RATE REQUIREMENTS FOR OFDMA SYSTEMS

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Abstract

In this paper a Radio Resource Allocation (RRA) and scheduling algorithm to maximize the satisfaction of users served by an Orthogonal Frequency Division Multiple Access (OFDMA) system is proposed. The Satisfaction Oriented Resource Allocation (SORA) algorithm, based on low complexity heuristics, divides the users into two sets: satisfied and unsatisfied. Then, it performs resource allocation taking advantage of channel frequency selectivity and the characteristics of each set. The main advantage of the proposed algorithm is the capacity of keeping a high number of users satisfied by resources from users that would be unsatisfied in any case.

I. Introduction

Beyond Third Generation (B3G) and future wireless mobile communications systems, such as the Long Term Evolution (LTE) of the 3rd. Generation Partnership Project (3GPP), have adopted Orthogonal Frequency Division Multiple Access (OFDMA) as the multiple access technology. OFDMA systems offers a high degree of flexibility to Radio Resource Allocation (RRA) algorithms. Due to the frequency selectivity, it is unlikely to find all subcarriers of a given user in a poor state. This characterizes frequency diversity. Moreover, due to the independence of user channels caused by distinct user positions in a cell, the subcarriers in poor channel states for some users, will be in good channel conditions for other users. This is the multi-user diversity.

It is expected that these future networks will be capable of providing a greater number of users with fulfilled Quality of Service (QoS) and higher system spectral efficiency compared to past systems. With this in mind, the trade-off between fairness and system spectral efficiency has been the focus of some works in this area [1-3]. However, from the system operator's point of view, the percentage of satisfied users is one of the most important measures to be maximized. The greater the percentage of satisfied users with good quality served with good quality and, consequently, the more profitable the network will be.

Non-Real Time (NRT) services do not have strict requirements regarding packet delay as do the Real Time (RT) services. Instead of this, NRT services require that the average data rate be above a given average data rate requirement [7]. Therefore, scheduling algorithms can profit by this long term data rate requirements, by assigning subcarriers to a given user only when they are in good channel state.

Many works have aimed to solve RRA problems in OFDMA systems based only on the current system conditions. The classical Margin Adaptive (MA) and Rate Adaptive (RA) problems [4] are examples of this. Also in [3] and [5] the authors emphasized in allocating resources to the users based on user normalized proportional constraints at each Transmission Time Interval (TTI) without taking into account the past allocations. As explained before, these algorithms are not interesting for NRT services.

Scheduling algorithms decide which users will have access to the system resources at the current TTI while RRA optimizes the efficiency of the resource utilization. It is clear that, as the decision of one have impact on the performance of the other, a joint optimization of both functionalities can increase the system performance. Some works like [1, 2] have followed this approach. However, the authors have aimed to achieve a good trade-off between system spectral efficiency and fairness. Besides, in [1], services with different data rate requirements were not considered in simulations.

Through our research in the RRA literature, we have observed that some works [3, 4] have proposed to split RRA problems into two parts: resource allocation and resource assignment (see more details in section III). This is an interesting approach because RRA problems are usually complex and hard to solve analytically. As the formulated problem in this work is a complex one, we also adopted this approach.

In this paper, we propose the Satisfaction Oriented Resource Allocation (SORA) algorithm, that is a two step RRA and scheduling algorithm to maximize the number of satisfied NRT users. The remainder of the paper is organized as follows. Section II presents the system modeling. Section III shows the problem formulation and conceived algorithm, and also describes the algorithms that are used for comparison. Finally in sections IV and V, the numerical results achieved by simulation and the conclusions are provided, respectively.

II. System Modeling

In the modeled OFDMA system, in order to overcome frequency selective fading and inter-symbol interference, the bandwidth of each subcarrier is chosen to be sufficiently smaller than the coherence bandwidth of the channel. Therefore, the N subcarriers of the system are modeled as flat Rayleigh fading channels correlated in time and frequency.

The subcarriers are shared by J terminals using a NRT service characterized by an average rate requirement R_j. It is assumed that the users have always a full data buffer. In addition, a fluid model is assumed for the traffic, i.e., the user data is completely divisible. The base station is assumed to have knowledge of the channel gain $g_{j,n}$ of each user j in each

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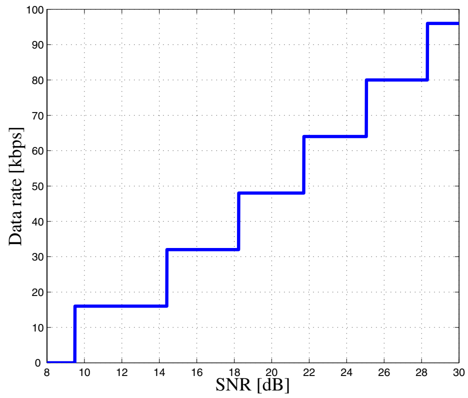

Figure 1: Link adaptation curve

subcarrier n. The Signal-to-Noise Ratio (SNR) $\gamma_{j,n}$ of user j in subcarrier n is defined as

$$\gamma_{j,n} = \frac{g_{j,n} \cdot p}{\sigma^2} \tag{1}$$

where p is the subcarrier transmit power, that is considered equal in all subcarriers, and σ^2 is the Additive White Gaussian Noise (AWGN) power.

The transmit data rate $\mathcal{R}_{j,n}$ in each subcarrier is given by [3]

$$\mathcal{R}_{j,n} = \Delta f \cdot \log_2 \left(1 + \frac{\gamma_{j,n}}{\Gamma}\right) \tag{2}$$

where Δf is the subcarrier bandwidth and

$$\Gamma = -\frac{\ln(5 \cdot BER)}{1.5} \tag{3}$$

is the SNR gap for the system Bit Error Rate (BER) requirements.

To represent the finite Modulation and Coding Schemes (MCSs) of the system, the capacity curve was sampled in the M-Quadrature Amplitude Modulation (QAM) modulations ($M = 2^m$; $m = 1, 2, 3, 4, 5$ and 6) as can be seen in Figure 1. The function that maps $g_{j,n}$ in $\mathcal{R}_{j,n}$ will be represented by $F(\cdot)$ in the rest of this work.

Once the subcarrier and bit allocation are defined by the scheduler, it is assumed that this information is sent via a separate control channel.

The main objective of our proposed algorithm is to maximize the number of satisfied users in the system. In this work, NRT users are satisfied if their average data rates are greater than their average data rate requirements. This definition is similar to the found in [7] for NRT service, like File Transfer Protocol (FTP) and World Wide Web (WWW). Also, the system capacity is defined as the offered load (number of users) in which 90 % of the users are satisfied.

III. Algorithm Descriptions

In this section we present all algorithms evaluated in this work, including our proposed one (SORA).

A. *Comparison algorithms*

In order to compare the performance of the proposed SORA algorithm, classical scheduling algorithms were used in this work. The classical algorithms are: Rate Maximization (RM) and Weighted Multi-Carrier Proportional Fair (WMPF). The description of these algorithms is presented in the following.

1) *Rate maximization*

One of the first problems studied in OFDMA RRA was the RM. The objective of this algorithm is to maximize the sum of the user data rates subject to the constraint that one subcarrier cannot be shared by more than one user at the same time. A detailed problem formulation can be found in [4].

The solution to this problem is very simple. Each subcarrier has to be assigned to the user that has the highest channel gain on it. In spite of its simple solution, the RM problem is not suitable regarding fairness issues. This algorithm can cause starvation of users at cell edge due to high path loss. This algorithm will be used to give the upper bound of total system data rate.

2) *Weighted multi-carrier proportional fair*

In [6], it was proposed the Multi-Carrier Proportional Fair (MPF) that is a generalization of the Single-Carrier Proportional Fair (SPF) algorithm to the case with multiple carriers. In our work, so as to compare with the performance of the SORA algorithm, we utilized a modified version of the MPF scheduling algorithm to deal with different QoS requirements. This is the WMPF scheduling algorithm that is similar to the one employed in [1]. At each TTI, the chosen user j^* to transmit in subcarrier n is given by

$$j^{\star} = \arg\max_{j} \left[\frac{R_j \cdot \mathcal{R}_{j,n}[k]}{T_j[k]}\right] \forall j \tag{4}$$

where $\mathcal{R}_{j,n}[k]$ is the data rate achievable by user j in subcarrier n at TTI k, R_j is the average data rate requirement of user j and $T_j[k]$ is the average/filtered data rate of user j at TTI k. The filtering of $T_j[k]$ is given by

$$T_j[k] = \left(1 - \frac{1}{t_a}\right) \cdot T_j[k-1] + \left(\frac{1}{t_a}\right) \cdot \mathcal{R}_j[k] \tag{5}$$

where $\mathcal{R}_j[k]$ is the effectively allocated rate to the user j at TTI k, and t_a is a filtering time constant.

B. *SORA algorithm*

The proposed algorithm in this paper, whose main objective is to maximize the user satisfaction, is presented in the following. Firstly, we provide the problem formulation and then the SORA algorithm is described.

1) *Problem Formulation*

Mathematically, we formulate our problem as

$$\max_{\mathbf{X}[k]} \quad \sum_{\forall j} U(r_j[k] - R_j)$$
$$\text{subject to} \qquad (6)$$
$$\sum_j x_{j,n}[k] \leqslant 1, \quad \forall \quad n,$$

where $\mathbf{X}[k]$ is the assignment matrix of elements $x_{j,n}[k]$ that assumes 1 if subcarrier n is assigned to user j, and 0 otherwise. $r_j[k]$ is the average data rate of user j until TTI k defined as $r_j[k] = b_j/(k \cdot T_0)$, where b_j is the number of bits sent by user j until TTI k and T_0 is the time length of one TTI. $E_{[k]}(\cdot)$ is the expected value taken in time variable k and $U(l)$ is the step function that is 1 if $l \geq 0$ and 0 otherwise.

2) Algorithm description

As done in several works in the literature, our proposed solution divides the problem (6) in two steps: The *Resource Allocation* step is responsible for determining how many subcarriers will be assigned to each user and the *Resource Assignment* step decides which subcarriers are assigned to each user.

The *Resource Allocation* step is shown in Algorithm 1. Firstly, the algorithm calculates the data rate $\Delta r_j[k]$ (for user j at the k^{th} TTI) necessary for achieving the user average rate requirement $\mathcal{R}_j$ in the TTI $K+1$.

Then, based on an estimate of the current data rate on a subcarrier using the mean channel gain among all subcarriers, the number of subcarriers demanded by the user j to achieve satisfaction on the next TTI m_j is calculated.

This required number of subcarriers represents the resources demanded by this user and, based on this estimate, two user sets will be generated from the user set $\mathcal{J}$:

- $\mathcal{S}$ is the set of satisfied users, and it is composed by the users that will still be satisfied if they do not transmit in this TTI. The users belonging to this set are characterized by having $m_j \leq 0$;
- $\mathcal{I}$ is the set of unsatisfied users, and this set is composed by users that have the average data rate lower than their rate requirement. The users belonging to this set are characterized by having $m_j > 0$;

The allocation set $\mathcal{A}$ will be composed by users allocated to transmit at this TTI. This set is generated by taking the user with the lowest estimated number of subcarriers in set $\mathcal{I}$ until the sum of allocated subcarriers $m_{alloc} = \sum_{j \in \mathcal{A}} m_j$ is higher than the number of subcarriers in subcarrier set $\mathcal{N}$. The notation $\#\mathcal{T}$ represents the cardinality of the set $\mathcal{T}$.

The *Resource Assignment* step is shown in Algorithm 2. At this step, each user in $\mathcal{A}$ has an opportunity to have one subcarrier assigned to it. When a user achieves the required data rate for the current TTI (Δr_j), it is moved to the satisfied set $\mathcal{S}$. If, at any time, all allocated users become satisfied, all the users in the unsatisfied set $\mathcal{I}$ are moved to the allocation set $\mathcal{A}$. If $\mathcal{I}$ is also empty, then the users in the satisfied user set

Algorithm 1 Resource Allocation Algorithm

```
for all j ∈ 𝒥 do
  Δr_j[k] ← R_j · k − r_j[k − 1] · (k − 1)
  if F(ḡ_j[k]) = 0 then
    if Δr_j[k] ≥ 0 then
      m_j ← #𝒩
    else
      m_j ← 0
    end if
  else
    m_j ← ⌈ Δr_j[k] / F(ḡ_j[k]) ⌉
  end if
end for
𝒮 ← {j|Δr_j[k] ≤ 0}    ℐ ← {j|Δr_j[k] > 0}    𝒜 ← ∅
if ℐ = ∅ then
  𝒜 ← 𝒮    𝒮 ← ∅
else
  m_alloc ← 0
  j* ← arg min_j {m_j | j ∈ ℐ}
  while m_alloc + m_j* ≤ #𝒩 and ℐ ≠ ∅ do
    𝒜 ← 𝒜 + j*    ℐ ← ℐ − j*
    m_alloc ← m_alloc + m_j*
    j* ← arg min_j {m_j | j ∈ ℐ}
  end while
end if
```

Algorithm 2 Resource Assignment Algorithm

```
order 𝒜 by ḡ_j[k]
j ← first element in 𝒜
while 𝒩 ≠ ∅ do
  n* ← arg max_n {g_j,n | n ∈ 𝒩}
  𝒩 ← 𝒩 − n*
  ℛ_j[k] ← ℛ_j[k] + F(g_j,n*)
  if ℛ_j[k] ≥ Δr_j[k] then
    𝒮 ← 𝒮 + j    𝒜 ← 𝒜 − j
  end if
  if 𝒜 = ∅ then
    if ℐ = ∅ then
      𝒜 ← 𝒮    𝒮 ← ∅
    else
      𝒜 ← ℐ    ℐ ← ∅
    end if
    j ← first element in 𝒜
  else
    j ← next element in 𝒜
  end if
  if j > #𝒜 then
    j ← first element in 𝒜
  end if
end while
```

$\mathcal{S}$ are moved to the allocation set $\mathcal{A}$ to get more resources. By allowing the satisfied user to get more resources, we reduce the probability of those users being unsatisfied in the next TTIs.

IV. Results

In this section we present the numerical results obtained from computational simulations. In this paper we study the case of a single cell system. The multi-cell case is left for a forthcoming paper. The main parameters used in the simulations are shown in the following.

The central operating frequency is 2 GHz. It is considered that there are 150 subcarriers available in the cell with

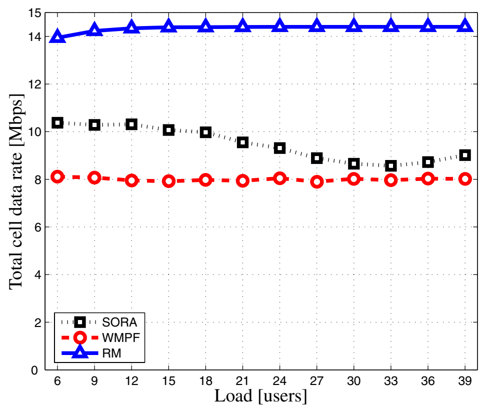

Figure 2: Total cell data rate for an equal average data rate requirement scenario

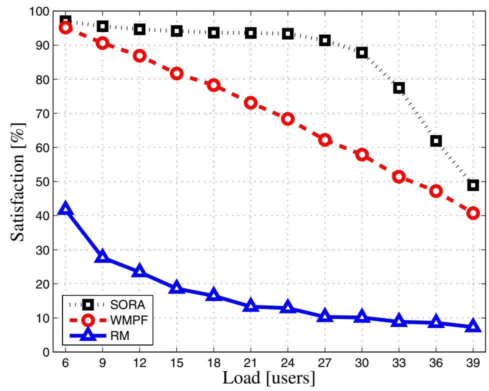

Figure 3: User satisfaction for an equal average data rate requirement scenario

a bandwidth of 15 kHz for each subcarrier. Regarding propagation, the path loss L [dB] at distance d [km] is calculated by $L = 128.1 + 37.6 \cdot \log_{10}(d)$. The shadowing standard deviation is 8 dB and the fast fading model is Typical Urban (TU). The modeled power budget has the following values. The noise power (p_{noise}) is -123.24 dBm per subcarrier, the total base station power is 20 W, and the cell radius is 1 km. Also, we assumed that the users are static and uniformly distributed in the cell coverage area. The minimum distance between the users and the cell antenna is 10 m. The resource allocation takes place in a TTI of 0.5 ms. The average data rate requirements evaluated in this work are 128 kbps, 256 kbps and 512 kbps. Finally, the time constant t_a used in the exponential filter in the WMPF scheduler is 50.

The results presented in this work are divided in two subsets. The first one comprises a scenario in which all users have the same average data rate requirement, that is 256 kbps. The other subset of results aims at analyzing the performance of the depicted algorithms when the users have different average data rate requirements (128 kbps, 256 kbps and 512 kbps uniformly distributed among users). In both result subsets, the user satisfaction and the total cell data rate are shown as a function of the number of users in the cell.

For each load presented from Figures 2 to 5, 200 realizations were performed in order to achieve statistical confidence. Moreover, the realizations have the time length of 300 TTIs. This time length was sufficient to achieve convergence of average user data rates for all algorithms.

Figures 2 and 3 show results related to the scenario with equal data rate requirements. Focusing firstly on the RM algorithm, we can see that, as it was expected, the RM algorithm outperforms the two other algorithms in the total cell data rate. This can be explained by the fact that this algorithm exploits the multi-user and frequency diversities, in such a way, that it schedules only the users with the best channel conditions in each subcarrier. Also note that the total cell data rate has a light increase with the system load due to the higher multi-user diversity. However, the RM scheduler does not take into account the user average rate requirements. This can be seen in Figure 3 where for the lower load in the figure (6 users) the satisfaction is only 41 %.

For the WMPF algorithm, that in this case is actually the MPF due to the equal data rate requirements, we can see that it had an intermediate performance for medium and higher loads regarding satisfaction. This behavior of WMPF can be explained by the fact that it lacks the intelligence of sacrificing the users with worst channel conditions in order to guarantee the QoS of other users. Note that in low loads the WMPF has a good performance in satisfaction. The system capacity for this algorithm is 9 users. It can be observed in Figure 2 that the total cell data rate of the WMPF algorithm is nearly constant with load.

The performance of the SORA algorithm shows that it achieves the objective discussed in section III. In Figure 3, it can be seen that for medium and high loads our algorithm outperformed the two other ones in satisfaction. In fact, the system capacity of the proposed algorithm is 28 users in this equal rate requirement scenario. This presents a capacity gain of 211 % compared to the WMPF. This gain can be explained simply by the smartness of the SORA algorithm to preempt the users with bad channel conditions so as to maximize the number of satisfied users. Figure 2 shows that SORA has a higher total cell data rate compared to WMPF for the simulated load range. This best performance is due to the resource assignment step of SORA, described in Algorithm 2, that allows the users in set $\mathcal{A}$ choose their best available subcarriers. On the other hand, WMPF, especially when there is many unsatisfied users with low filtered data rate T_j, does not allocate the best subcarriers for the users because other users with low T_j have higher priority.

In the second subset of results presented in Figures 4 and 5, the scenario with different user data rate requirements is analyzed. The RM scheduling algorithm has a similar behavior in this scenario, related to the other algorithms, compared to the equal rate requirement scenario in Figures 2 and 3. This is expected, since this algorithm does not care for user rate requirements and only few users (the best ones) have

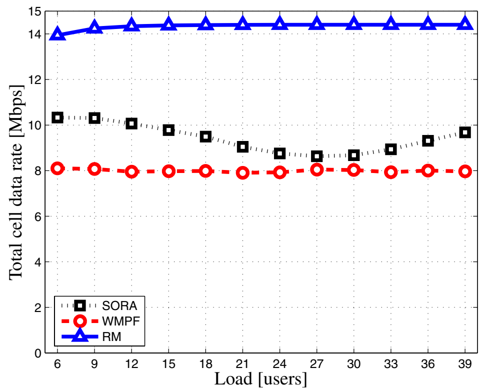

Figure 4: Total cell data rate for a different average data rate requirement scenario

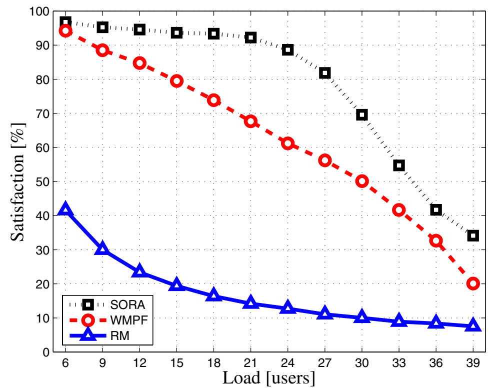

Figure 5: User satisfaction for a different average data rate requirement scenario

opportunity to transmit. The satisfied users, that are the ones with best channel conditions in this algorithm, usually achieve average data rates much larger than the maximum average data rate requirement considered in this study that is 512 kbps. This is the reason why the performance of this algorithm is independent of the scenarios utilized in our study.

As it can be seen in Figure 5, the performance of WMPF in satisfaction is worse than our proposed algorithm. This scenario is even more difficult to all algorithms due to the new decision variable added: the different average user data rate requirements. The WMPF in this case tries to have a good balancing among channel conditions, average user data rate requirements, and the effect in the current average user data rate by the past allocations. Regarding the total cell data rate of WMPF, we can see that the scenario with different user rate requirements has not caused a significant change.

Finally, the performance of the SORA algorithm in satisfaction (see Figure 5), as in the equal average user data rate requirements scenario, was superior to the compared algorithms. However, in this case the gain over WMPF is lower. In this scenario, the capacity of our algorithm is 22 users while the capacity of WMPF is 8 users, leading to a gain of nearly 175 %. It is worthy to mention that even in the complex scenario with different average user rate requirements, SORA maintained the superiority over the other ones. As commented before, the SORA algorithm has the intelligence of preempting the users with bad channel conditions so as to maximize the number of satisfied users.

V. Conclusions and Perspectives

In this paper, we proposed a new radio resource allocation algorithm to increase the system capacity by dynamically adapting to the user channel conditions and requirements in an orthogonal frequency division multiple access system. The satisfaction oriented resource allocation algorithm divides users into two subsets to allocate the resources based on the characteristics of each set. The simulation results show that the SORA algorithm outperforms the classical weighted multi-carrier proportional fair algorithm in cell throughput and satisfaction. The SORA algorithm was capable of keeping a high number of satisfied users by preventing that resources were given to users with too poor channel condition while other users still could be satisfied.

The next steps are to evaluate the SORA algorithm for a multi-cell environment, propose a modification of it to deal with real time users and verify the robustness against limited feedback and errors in channel information.

VI. Acknowledgments

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