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Reducing the interference by adapting the power of OFDM for mMTC

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***Abstract*—The Fifth Generation of mobile communications (5G) is being standardized based on Orthogonal Frequency Division Multiplexing (OFDM) waveforms. The high out-of-band emissions (OBE) are one of the main drawbacks of OFDM, which reduce the spectral efficiency and force us to leave wide guard bands. A strong candidate to replace OFDM is filtered-OFDM (f-OFDM) which solves the mentioned issue and keeps the backward compatibility. However, it increments the inter-symbol interference (ISI) due to the use of digital filters. We propose a new technique to overcome this problem. It is based on shaping the power of OFDM by the scheduler according to the demanded rates and channel quality of the users, while decreasing the OBE and avoiding the ISI increase. The interference generated by our proposed technique on a narrow-band signal based on legacy OFDM is analyzed. Moreover, simulations are performed to validate the theoretical analysis and some examples of implementation are also provided in the context of 5G evolution.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been adopted as the transmission waveform in the existing Fourth Generation (4G) networks, such as Long Term Evolution (LTE). Recently, the Third Generation Partnership Project (3GPP) has also proposed to integrate Machine Type Communications (MTC) in the existing LTE network keeping the same waveforms and reusing as far as possible the current configuration [1]. The 3GPP is defining a New Radio (NR) for the Fifth Generation (5G) which will be OFDM-based [2]. Among others, 5G should be able to provide massive MTC (mMTC) that should coexist with enhanced Mobile Broad-Band services (eMBB).

Despite the fact that OFDM-based waveforms have many advantages such as robustness against multi-path fading and ease of implementation, they also have severe drawbacks, such as high peak-to-average power ratio (PAPR) and high side lobes in frequency domain, among others. Focusing on the high side lobes, they force us to leave wide guard bands at both sides of the band in order to reduce the out-of-band emissions (OBE). Therefore the valuable spectral efficiency is reduced.

In the particular case of the downlink, filtered-OFDM (f-OFDM) waveform [3] has been proposed to reduce the OBE while keeping the backward compatibility with the deployed network. However, the use of digital filters increases inter-symbol interference (ISI) and the length of the cyclic prefix (CP) should be increased, so reducing also the efficiency. We propose a new technique which consists in adapting the power of the OFDM signal with a spectral mask, which is dynamically designed by the scheduler according to the demanded rates and the channel quality of the served user equipment (UEs). The scheduler will allocate the edge subcarriers to those users that require a lower power. Therefore, the undesirable OBE are reduced while the performance is guaranteed. Furthermore, this technique does not increase the ISI and has therefore the same benefits as f-OFDM without its disadvantages. We will denote our proposed technique as Power Adaptation (PA) technique.

The scheduler will consider the signal to interference plus noise ratio (SINR) of the UEs in order to perform the resource allocation (RA) and power optimization to decrease the OBE and fulfill their data rate requirements. Moreover, in the context of spectrum sharing for mMTC, [4] shows that f-OFDM reduces the OBE allowing the deployment of additional signals in its guard-bands. Hence, using the same scenario, we replace the f-OFDM by the PA-OFDM to evaluate its performance when additional signals are allocated in its guard-bands. We analyze the performance in terms of SINR, and then we propose a heuristic RA algorithm based on the computed SINR, combined with the Water-Filling algorithm [5] which provides a good performance for practical systems.

The remainder of the paper is organized as follows. In Section II, we provide an explanation of the system model under study. In Section III, we analyze the SINR for OFDM with the PA technique and we present our proposed RA algorithm. In Section IV, we show some numerical results to validate the theoretical analysis and provide some understanding of the best configurations for PA. Finally, in Section V, some conclusions are pointed out.

Notation: x denotes a scalar value. $\mathbf{x}$ denotes a matrix where $x[m,n]$ denotes the element of the m-th row and n-th column. $\lfloor x \rfloor$ stands for the smallest integer lower than x. $mod(x,y)$ is the modulo operation which retrieves the remainder of dividing x/y. $*$ denotes the convolution operation. $\circ$ denotes the component-wise product of two vectors.

II. System Model

We consider two multi-carrier signals transmitted in contiguous spectral resources in the downlink (see Fig. 1). These two signals are transmitted from two different base stations (BS) ($BS_i,\ i \in \{1,2\}$) towards several UEs. The broad-band signal from BS_1 has K_1 data subcarriers, which contain the multiplexed information to several eMBB UEs

($u_1 \in \{0, 1, \ldots U_1 - 1\}$). The narrow-band signal from BS_2 has K_2 data subcarriers, addressed to several mMTC UEs ($u_2 \in \{0, 1, \ldots U_2 - 1\}$). With this scenario we are addressing the case of a narrow-band mMTC signal being deployed in the guard-band of the eMBB signal. We will use PA-OFDM for the eMBB in order to facilitate this contiguous transmission and a better utilization of the spectrum.

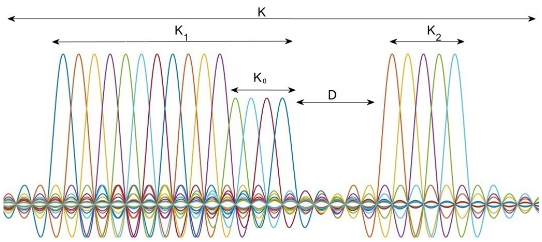


Fig. 1. Parameters of two contiguous multi-carrier signals.

Let $\mathbf{s}_i$ denote a vector containing the set of $1 \times K_i$ complex information symbols to be transmitted, which belong to a QAM constellation with unit power $E\left[|\mathbf{s}_i|^2\right] = 1$. Note that, in order to ease the analysis we up-sample the two signals. Then, $\mathbf{s}_i$ is mapped to $\mathbf{s}_{0,i}$ of length $K \geq K_1 + K_2$ according to

$$s_{0,i}[k] = \left\{ \begin{array}{cc} s_i[k] & k \in \mathcal{A}_i \\ 0 & k \notin \mathcal{A}_i \end{array} \right\}, \tag{1}$$

where $\mathcal{A}_i$ contains the mapping indices. Fig. 2 shows the new signals $s_{0,1}[k]$ and $s_{0,2}[k]$, with "0" corresponding to the unmodulated subcarriers to allow different signals to be overlayed. Note that $\mathcal{A}_1$ and $\mathcal{A}_2$ are disjoint sets.

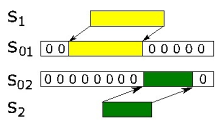


Fig. 2. Complex symbol mapping.

The modulated signal is obtained in blocks of K samples according to the following expression

$$v_i[m] = \frac{1}{K} \sum_{k=0}^{K-1} b_i[k] s_{0,i}[k] e^{j\frac{2\pi k m}{K}}, \tag{2}$$

where m indicates the time instant and $\mathbf{b}_i(K_i \times 1)$ is a vector where $b_i^2[k]$ is the power of the symbols $\mathbf{s}_{0,i}$. Note that, even though $\mathbf{b}_i$ is defined for both signals ($i \in \{1, 2\}$), the PA technique is only applied in BS_1. Before sending each block of K samples, a cyclic prefix (CP) is added, so that the expression of the signal to be transmitted is

$$v_{cp,i}[m] = \left\{ \begin{array}{cc} v_i[m] & m = 0 \ldots K-1 \\ v_i[m+K] & m = -L_{CP} \ldots -1 \end{array} \right\}, \tag{3}$$

where L_{CP} is the length of the CP. Note that, $\mathbf{b}_i$ will be dynamically computed by the scheduler in order to reduce the OBE and satisfying the rates of all the UEs.

When the two contiguous multi-carrier signals are simultaneously transmitted (see Fig. 1), the received signal at a u_2-th mMTC UE of interest is given by

$$z[m] = h_{1,u_2}[m] * v_{cp,1}[m] e^{-j\frac{2\pi m \epsilon}{K}} + h_{2,u_2}[m] * v_{cp,2}[m] + n[m], \tag{4}$$

where $\mathbf{v}_{cp,2}$ and $\mathbf{v}_{cp,1}$ are precisely the reference and interference signal vectors respectively, where the mismatch between their carrier frequencies is characterized by $\epsilon = \bmod (D, \Delta f) / \Delta f$, where D is the spectral distance of the two multi-carrier signals measured in Hz (see Fig. 1) and Δf is the subcarrier spacing. Moreover, $\mathbf{h}_{i,u_2}$ is the multi-path channel response representing small-scale fading $E\left[|\mathbf{h}_{i,u_2}|^2\right] = 1$, between the BS_i and u_2-th UE, and $n[m]$ is the Additive White Gaussian Noise (AWGN) with distribution $n[m] \sim \mathcal{CN}(0, \sigma_n^2)$.

Given (4), assuming the CP is long enough to mitigate the ISI, we should remove it and expanding the DFT, it is straightforward to see that the received signal at subcarrier $k_0 \in \mathcal{A}_2$ of u_2-th mMTC UE is given by the addition of the reference signal and the interfering one

$$y[k_0] = y_1[k_0] + y_2[k_0] + w[k_0], \tag{5}$$

where $w[k]$ is the noise term in the frequency domain with distribution $w[k] \sim \mathcal{N}(0, \sigma_w^2)$, where $\sigma_w^2 = K\sigma_n^2$,

$$y_2[k_0] = H_{2,u_2}[k_0] s_2[k_0], \tag{6}$$

$$y_1[k_0] = \sum_{l \in \mathcal{A}_1} H_{1,u_2}[l] b_1[l] s_1[l] f[l - k_0], \tag{7}$$

$\mathbf{H}_{1,u_2}$ and $\mathbf{H}_{2,u_2}$ are vectors of size $(K \times 1)$ which represent the channel response in the frequency domain for each of the two signals respectively to the u_2-th mMTC UE, defined as

$$H_{i,u2}[k] = \sum_{m=0}^{K-1} h_{i,u2}[m] e^{-j\frac{2\pi k m}{K}}, \tag{8}$$

$f[l - k_0] = f[d + \epsilon]$ is the $sinc$ interference defined as

$$f[d+\epsilon] = \frac{\sin(\pi(d+\epsilon))}{K \sin\left(\frac{\pi(d+\epsilon)}{K}\right)} \exp\left(\frac{j\pi(d+\epsilon)(K-1)}{K}\right), \tag{9}$$

where $d = \lfloor D/\Delta f \rfloor$ is the integer number of subcarrier spacings that separate the two multi-carrier signals (see Fig. 1). Note that, (7) reflects the inter-carrier interference (ICI) produced by $\mathbf{v}_{cp,1}$, (3).

III. SINR Analysis and Interference Reduction

Following [4], the power of the interference signal received at subcarrier k_0 of u_2-th mMTC UE of the reference signal $y_2[k_0]$ can be expressed by

$$\sigma_{I,u_2}^2[k_0] = E\left[\left|\sum_{l \in \mathcal{A}_1} H_{1,u_2}[l] b_1[l] s_1[l] f[|l - k_0|]\right|^2\right] = \\ = \sum_{l \in \mathcal{A}_1} E\left[|H_{1,u_2}[l]|^2\right] E\left[|b_1[l]|^2\right] |f[|l - k_0|]|^2 . \tag{10}$$

Note that, as we mentioned before, $\mathbf{b}_1$ varies with time. Therefore, the SINR of the reference signal (6) for the u_2-th mMTC UE is

$$SINR_{u_2} = \frac{1}{K_2} \sum_{k_0 \in \mathcal{A}_2} \frac{E\left[|H_{2,u_2}[k_0]|^2 \right]}{\sigma^2_{I,u_2}[k_0] + \sigma^2_w}. \quad (11)$$

Given (10) and (11), the scheduler of BS_1 should minimize $\sigma^2_{I,u_2}[k_0], \forall k_0 \in \mathcal{A}_2$, which corresponds to maximizing the $SINR_{u_2}$, by choosing $\mathbf{b}_1$, according to the demanded rates and the channel quality of the U_1 eMBB UEs at a given time instant. However, according to (10), the BS_1 additionally needs not only the channel state information of all mMTC UEs, but also their RA information (only available in BS_2), which might correspond to a non-realistic situation. Hence, assuming that the BS_1 does not have any information about mMTC UEs, we will minimize the interference without taking into account the factor $\mathbf{H}_{1,u_2}$, which corresponds to the worst scenario.

As we mentioned before, the K_1 available data subcarriers of $\mathbf{v}_{cp,1}$ are shared by the U_1 eMBB UEs, hence the minimization problem can be described as

$$\min_{\mathbf{X},\mathbf{b}_1} \sum_k |f[|k-k_0|]|^2 \sum_{u_1} X[k,u_1] |b_1[k]|^2, k_0 \in \mathcal{A}_2 \quad (12)$$

$$\text{s.t.} \sum_{u_1} X[k,u_1] = 1, \quad \sum_k \sum_{u_1} X[k,u_1] |b_1[k]|^2 \leq P_{max},$$
$$r_{req}[u_1] \leq r_{gra}[u_1] =$$
$$= \Delta f \sum_k X[k,u_1] \log_2 \left(1 + \frac{|b_1[k]|^2 |H_1[k,u_1]|^2}{\sigma^2_{I,u_1}[k] + \sigma^2_w} \right), \quad (13)$$

where

$$\mathbf{H}_1(K_1 \times U_1) = \begin{bmatrix} \mathbf{H}_{1,u_1=0} & \mathbf{H}_{1,u_1=1} & \cdots & \mathbf{H}_{1,u_1=U_1-1} \end{bmatrix}, \quad (14)$$

P_{max} is the maximum available power at the BS_1, $\mathbf{r}_{req}(U_1 \times 1)$ and $\mathbf{r}_{gra}(U_1 \times 1)$ are the requested and granted rates respectively, defined here as Shannon rates [6], and $\mathbf{X}(K_1 \times U_1)$ is the assignment variable defined as

$$X[k,u_1] = \left\{ \begin{array}{ll} 1 & \text{resource } k \text{ assigned to user } u_1 \\ 0 & \text{resource } k \text{ not assigned to user } u_1 \end{array} \right\}, \quad (15)$$

and $\sigma^2_{I,u_1}[k]$ is the ICI caused by the mMTC UEs. However, according to [4], this term is negligible due to the fact that not only the mMTC signal is a narrow-band signal that rises a low ICI, but also the performance of eMBB signal in terms of error probability is not deteriorated when some of the edge subcarriers are polluted by some interference. Thus, we can omit this value in order to ease the optimization problem.

A. Optimal Solution

The expression given in (12) is a mixed-integer optimization problem due to the assignment variable $\mathbf{X}$ combined with $\mathbf{b}_1$. In order to find the optimal solution, which corresponds to the lowest OBE, we should perform an exhaustive search (ES) over the $2^{K_1 \times U_1}$ possible combinations of $\mathbf{X}$, and for each case perform the following optimization problem

$$\min_{\mathbf{b}_1} \sum_k |f[|k-k_0|]|^2 |b_1[k]|^2, k_0 \in \mathcal{A}_2 \quad (16)$$

$$\text{s.t.} \quad r_{treq} \leq \Delta f \sum_u \sum_k \log_2 \left(1 + \frac{|b_1[k]|^2 |H'_1[k]|^2}{\sigma^2_w} \right),$$
$$\sum_k |b_1[k]|^2 \leq P_{max}, \quad (17)$$

where

$$r_{treq} = \sum_{u_1=0}^{U_1-1} r_{req}[u_1]. \quad (18)$$

$$\mathbf{H}'_1(K_1 \times 1) = \sum_{u_1=0}^{U_1-1} \mathbf{X}(1\ldots K_1, u_1) \circ \mathbf{H}_{1,u1}. \quad (19)$$

The described problem is convex, and it can be solved using Langrage multipliers with two restrictions. However, it will be infeasible if the BS_1 does not have enough power to grant the demanded rates by the UEs. In this case the required data rates should be lowered or the available power should be increased.

An alternative way to solve (16) is using the modified Water-Filling (WF) algorithm to compute each value of $\mathbf{b}_1$ considering only the rate restriction; the total power restriction will be handled later. That corresponds to the well-known weighted sum power minimization problem [5] and it is more efficient than using two restrictions, so

$$|b_1[k]|^2 = \left(\frac{\lambda}{|f[|k-k_0|]|^2} - \frac{\sigma^2_w}{|H'_1[k]|^2} \right)^+, \quad (20)$$

where λ is defined as

$$\lambda = \sigma^2_w \left(2^{r_{req}[u_1]/\Delta f} \left(\prod_{k=1}^{K_1} \frac{|H'_1[k]|^2}{|f[|k-k_0|]|^2} \right)^{-1} \right)^{\frac{1}{K_1}}. \quad (21)$$

Next step will be to check the power restriction condition, if $\mathbf{b}_1$ does not satisfy it, we reduce the demanded rate and recompute $\mathbf{b}_1$ again. Finally, once we have computed the $2^{K_1 \times U_1}$ possible solutions, we must choose the one that has the minimum OBE, satisfying (16).

B. Proposed Low-Complexity Resource Allocation

We propose a heuristic RA algorithm, which requires much less processing effort to achieve similar results compared to the ES. The main idea is to reduce the amplitude value of those subcarriers which are placed at the edges of the signal band, close to the mMTC signals. Because the ICI caused by one subcarrier decays linearly with the distance from it, measured in Hertz, the edge subcarriers are mainly the ones to rise the OBE interfering to the adjacent mMTC. Hence, the edge resources will be allocated to the UEs that have the highest channel gain $\mathbf{H}_1$ and, at the same time, the lowest

TABLE I
PROPOSED LOW-COMPLEXITY RA ALGORITHM

```
k_l = 1; % Start from the left edge
k_r = K_b; % Start from the rigth edge
for q=1:I
   [∼,idx_l]=sort(H_1(:,k_l),'descend');
   [∼,sel_l]=min(r_req(idx_l(1:2)));
   [rq_l]=RequiredResources(r_req(sel_l),H_1);
   % Repeat the same code for k_r
end
```

TABLE II
SIMULATION PARAMETERS

$\mathbf{K}$	1024 subc.	**Num. Chan. Realizations**	7×10^3
$\mathbf{K_1}$	600 subc.	**Channel Model**	ETU
$\mathbf{K_2}$	up to 12 subc.	$\mathbf{\Delta f}$	15 KHz
$\mathbf{K_s}$	12 subc.	**CP Length**	72 samples

requested rate $\mathbf{r}_{req}$. These two conditions will guarantee that $\mathbf{b}_1$ at edge subcarriers will be as low as possible, because the allocated UEs at both edge bands only need a tiny amount of power to satisfy their requirements. Then, the UEs, that have a low channel gain or demand a high data rate, are allocated at the middle of the band with a higher power. Therefore, the PA is a power control system that balances the power, reducing the OBE and guaranteeing the overall performance. Table I shows the pseudo-code, that selects the eMBB UE with the lowest rate among the two (or more) UEs with the highest channel gain. Then, the needed resources for the chosen UE are computed, assuming that P_{max} is equally distributed for all UEs. The proposed search method can be efficiently executed in terms of time, outperforming the ES that needs to try $2^{K_1 \times U_1}$ possible combinations.

Additionally, in practical systems the minimum amount of resources that can be assigned to each UE is a set of K_s subcarriers, often denoted as resource block (RB). Hence, the K_1 subcarriers are grouped into K_b RBs ($K_1 = K_b \times K_s$). This consideration can be easily adopted in the mentioned RA algorithm, and for the sake of space we omit the details.

IV. NUMERICAL RESULTS

In this section we show some simulation results to verify the theoretical analysis and the effectiveness of our proposed RA.

A. Validation of the theoretical analysis

Table II shows the main parameters used in the simulations of this sub-section, based on the numerology of LTE with $10MHz$ bandwidth. For the simulation results of Fig. 3, $\mathbf{b}_1$ is defined as

$$b_1[k] = \left\{ \begin{array}{cc} 1 & k = 0 \dots (K_1 - K_0 - 1) \\ 10^{\alpha/20} & k = (K_1 - K_0) \dots (K_1 - 1) \end{array} \right\}, \quad (22)$$

where $\alpha = -3dB$ and $K_0 = K_s$ (one RB). Fig. 3 shows the performance according to our analytical model and the simulation results of SINR for OFDM with and without the PA technique. We can see that our model fits well the simulation results and the OFDM with PA outperforms traditional OFDM (without PA) by about 2.5dB.

B. Spectral Efficiency of PA

Currently, in LTE, the spectral efficiency is defined as

$$\eta(\%) = \frac{\Delta f \times K_1}{BW} = \frac{15KHz \times K_1}{10MHz}, \quad (23)$$

and it has the value $\eta = 90\%$. The PA technique can improve this value by increasing the number of the available subcarriers K_1, while keeping the same power of interference due to the OBE σ_I^2 at a reference subcarrier k_0. In this example, let us define the set $\mathcal{A}_1 = [-511 \dots 512]$, we focus on $k_0 = 330$, and $\mathbf{b}_1$ is defined again by (22), where the different values of

TABLE III
EXAMPLE OF ENHANCED EFFICIENCY USING PA-OFDM.

α (dB)	K_0 for each end of the band	K_1	η
-3	12	608	91.2%
-3	24	616	92.4%
-6	12	616	92.4%
-6	24	624	93.6%
-3	12	622	93.3%
-6	12		

TABLE IV
COMPARISON BETWEEN ES AND PROPOSED RA ALGORITHM

	Number of threads	**Time [ms]**
ES + WF	1	104.3
proposed RA + WF	1	31.21

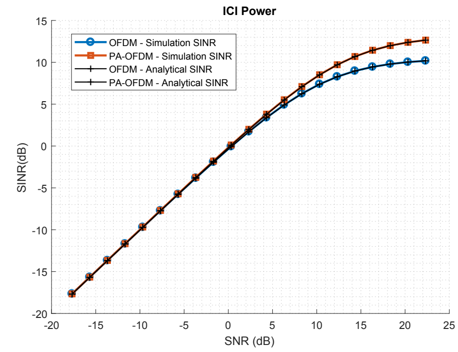


Fig. 3. Comparison of SINR with $\epsilon = 0.5$ and $K_1 = 600$.

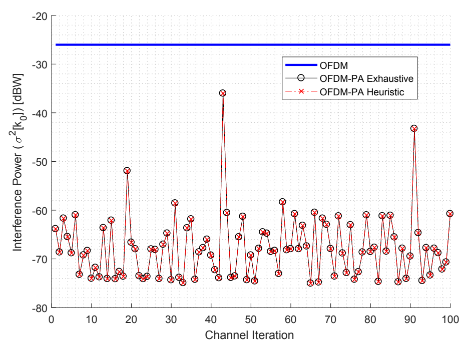
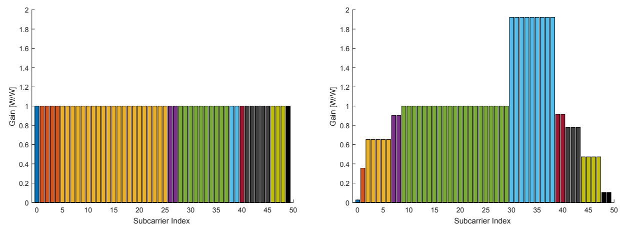


Fig. 4. Comparison of the performance of the scheduling.

TABLE V
EXAMPLE OF RA FOR PA-OFDM

u_1	SNR(dB)	α(dB)	$SNR_{equivalent}$(dB)	$\mathbf{r}_{req}$	$\mathbf{r}_{gra}$ OFDM	$\mathbf{r}_{gra}$ PA-OFDM	Granted RB OFDM	Granted RB PA-OFDM
0	28.59	-15.94	12.65	51.36	113.99	51.36	1	1
1	17.96	-03.26	14.70	236.77	287.48	236.77	4	4
2	07.13	0	08.47	936.48	661.22	757.13	21	21
3	12.46	-0.39	12.07	98.35	101.25	98.35	2	2
4	26.47	2.84	29.30	1050.77	980.57	1051.60	10	9
5	03.18	-0.45	02.73	36.54	38.95	36.54	2	2
6	21.55	-4.49	17.06	68.36	86.03	68.36	1	1
7	16.27	-1.85	14.42	290.48	326.31	290.48	5	5
8	09.68	-1.10	08.58	109.40	121.07	109.40	3	3
9	24.28	-9.83	14.44	69.87	96.85	116.35	1	2



(a) Conventional scheduling. (b) Smart scheduling.

Fig. 5. Illustration of the scheduling of OFDM with and without PA technique.

α and K_0 are defined in the first column of Table III. In order to make this example more realistic we have set $K_0 = cK_s$, where ($c \in \{1, 2, \ldots K_b\}$) making K_0 correspond to c RBs. In Table III, we can see the improvement of η up to 93.6% with PA-OFDM, and it is similar to f-OFDM [4], but without the increase of ISI.

C. RA with PA-OFDM

In Fig. 4, we can see a comparison of the performance of our proposed RA algorithm compared to the ES and the traditional OFDM, for the case of $U_1 = 2$ UEs sharing $K_b = 4$ RBs with 100 channel iterations. The measured interference power $\sigma^2[k_0]$ corresponds to the contiguous subcarrier of the signal band ($k_0 = K_b \times K_s + 1$). We can clearly see that our proposed method has the same performance as the ES using smaller execution time, as it is shown in Table IV (simulated in Intel Core-i7@3.7 GHz with up to 8 threads) and always outperforms the traditional OFDM. When U_1 and K_b (or K_1) become higher, the ES is not feasible in realistic systems. On the contrary, our RA method can achieve a low OBE in realistic systems.

Once the proposed method has been validated, we provide an example, whose details are described in Table V. It shows $U_1 = 10$ UEs sharing $K_b = 50$ RBs in one OFDM symbol, where each user has its own measured Signal to Noise Ratio (SNR_i) and demanded rate $\mathbf{r}_{req}$. Fig. 5a, shows the typical power per subcarrier in the current LTE system. Note that in this example the UE $u_1 = 4$ is demanding a high data rate and the system cannot satisfy this requirement with traditional OFDM (see Table V). Fig. 5b presents the variable power per subcarrier of the PA technique, where the UEs that are demanding low rates are allocated the edge RBs with the lowest power, and the others are placed in the middle with a higher power. Note that the rate demanded by UE $u_1 = 4$ is satisfied thanks to the use of the amount of power left due to the attenuation of the edge UEs. This example shows that PA also brings the possibility to grant more flexibility for the RA helping to better satisfy the rate required by all UEs.

V. CONCLUSIONS

In this work we have proposed a new PA technique applied to OFDM. Based on the SINR analysis, we have seen that it is capable of reducing the OBE and avoiding the ISI increase due to the filtering, making it a good candidate with respect to traditional OFDM or f-OFDM, not only to be adopted in the current 4G systems, but also for the next 5G where mMTC and eMBB must coexist.

Numerical results have verified the effectiveness of our proposed RA algorithm for a realistic mobile communications scenario, showing that OFDM with PA is a good solution that enables an efficient use of spectral gaps with a greater flexibility to satisfy the demands of the UEs.

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