Power Allocation for Energy-Efficient Downlink NOMA Systems

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***Abstract*—As a potential multiple access scheme for Non-orthogonal Multiple radio Access (NOMA) is considered a promising technique for the fifth-generation mobile networks (5G). This technology will improve both Spectral Efficiency (SE) and flexibility of radio resource allocation for users as it will be shown. Green Radio (GR), which concentrates on Energy Efficiency (EE), is becoming a sought-after trend in the process of a future for an energy-efficient system. In this paper, we seek to optimize the power allocation problem in order to improve EE for downlink NOMA systems. For this, a low complexity power allocation approach for each user has been proposed. Optimization problem's solution is achieved when optimal power values are obtained. The simulation results obtained show the effectiveness of our proposed allocation strategy. NOMA actually offers better improvements in EE compared than conventional non-orthogonal access.**

***Index Terms*—NOMA, Power Allocation, EE**

I. INTRODUCTION

During recent years, Telecommunication sector has witnessed a continuous growth in traffic, an increasing proliferation of smart devices and an important emergence of various applications have appeared [1]-[2]. These challenges have pushed limits of the actual generation, and pointing toward a need for a fifth generation mobile communication (5G) of cellular technology.

Excessive power usage in such networks is a critical issue for the mobile operators. Today, Information and Communication Technology (ICT) infrastructures consume more than 3% of the world's energy, of which about 60% is caused by base stations (BS) [2]. However, the increase in traffic shouldn't be at the expense of increased energy consumption. For that, research's effort continue to provide solutions. For example, Green Radio (GR) strategy is proposed [3]. This option, named GR, which focuses on EE as it will be indicated, is becoming a sought-after trend for future energy-efficient wireless communications[4]-[5]. Smarter and more rational management of radio resources as well as a scalability of multiple access systems have been adopted [5].

To satisfy requirements, enhanced technologies are necessary. So far, series of techniques and schemes which are considered as potential candidates addressing challenges of 5G have been proposed. The huge can be such: cell densification, millimeter wave communication, new modulation, new coding schemes and advanced radio access [1]-[2]. Recently a more flexible multi-user access schemes have been suggested and studied. Research efforts have led to choose a non-orthogonal multiple access as it will be described. This is known as NOMA. This new technology stands out as an available candidate for 5G [7].

Various aspects of NOMA have been studied. Earlier performance evaluations for those systems could be used for both downlink and uplink. Allocation of radio resources in NOMA networks has been the subject of numerous studies and the main have looked for improving SE. Besides, EE index is becoming a crucial performance measure and a trend in the process of an energy-efficient system [4]-[5]. In contrast to SE-based resource allocation schemes in which total transmit power is fixed, EE-based schemes adaptively adjust power levels according to channel behaviors [6].Multiple approaches works have been studied in the process looking to improve EE in NOMA systems [8]-[9].

Despite the existing literature, there is a lack of systematic approach to NOMA resource allocation from an optimization mathematical theory point of view. In this work, we consider power allocation to improve EE for NOMA systems. One hopes to create an energy-efficient system. The rest of this paper is organized as follows. First, the system model illustrating the concept of downlink NOMA application with a BS and two users is described. Problem Formulation and proposed power allocation approach is given in Section III. Section VI provides an evaluation of the energy performance of the proposed allocation approach through numerical simulations. Finally, Section V concludes the paper and indicates perspectives.

II. SYSTEM MODEL

In order to have a low receiver's complexity, we consider a simple case where only two users are assigned to the same sub-channel. For this, we consider a single-cell downlink NOMA system where a BS serves simultaneously users respectively named U_1 and U_2. This consideration is important because it also limits error propagation. U_1 and U_2 are randomly distributed in the cell.

A perfect channel state information's knowledge is supposed be available at the BS. The modulation symbol of the user U_k is denoted s_k with an unitary energy: $E[|s_k|^2] = 1$.

In our NOMA system, it is assumed that the data symbols of the user U_k are superimposed, s_1 and s_2 are thus coded with distinct transmission powers P_1 and P_2 on the same subcarrier, respectively. The transmitted signal is represented by:

$$x = \sqrt{P_1}.s_1 + \sqrt{P_2}.s_2 \tag{1}$$

Where the total transmit power is:P=P_1+P_2 .

It's also It's also assumed that the BS and the users each having a single antenna. The signal received by the user could be written as follows:

$$y_k = h_k.x + w_k \tag{2}$$

where h_k is the coefficient of the channel between the users U_k and the BS. w_k refers to an Additive White Gaussian Noise (AWGN), including intercellular interference. The spectral power density of w_k is N_0. Successive Interference Cancellation (SIC) process for NOMA is implemented at the receiver. According to SIC decoding order, for a decreasing gain of the channel normalized by N_0. Define, $H_k = \frac{|h_k|^2}{N_0}$ as equivalent channel gain of the user U_k in the following.

Let's assume the user U_1 is in the center of the cell with better channel quality. This is considered as a strong user. While the user U_2 is the user at the edge of the cell with a lower channel quality called a weak user. According to SIC decoding order, the optimal order is in the order of the decreasing gain. Without loss of generality, it is assumed that $H_1 > H_2$. According to NOMA's principal, more power is allocated to the weak user to facilitate the SIC process and ensure fairness (further from the BS, more allocated power), i.e.$P_1 \leq P_2$.

Assuming successful decoding of the signal, then, in accordance with Shannon's capacity law, the strong user throughput's can be written as:

$$R_1 = W.log_2(1 + P_1.H_1) \tag{3}$$

Where W is the total BS's available bandwidth. The weak user U_2 does not perform SIC and deals the strong user's signal as noise. The throughput of U_2 can therefore be expressed like:

$$R_2 = W.log_2(1 + \frac{P_2.H_2}{1 + P_1.H_2}) \tag{4}$$

Then, the total throughput will be:

$$R = W.log_2(1 + P_1.H_1) + W.log_2(1 + \frac{P_2.H_2}{1 + P_1.H_2}) \tag{5}$$

III. PROBLEM FORMULATION

Looking for maximizing EE by properly allocating the BS power to users. Let consider the EE metric, commonly defined as the ratio of throughput to energy consumption, is written as:

$$EE = \frac{R}{P + P_c} \tag{6}$$

Where P is the total transmitted power and P_c is the constant power consumption of the circuit. The impact of the circuit power on the EE maximization will be discussed later for an energy optimization goal. The mathematical model of the optimization problem can be expressed as:

$$\begin{aligned} MaxEE &= \frac{R}{P + P_c} \\ C1 &: P_1 + P_2 = P \\ C2 &: 0 \leq P_1 \leq P_2 \end{aligned} \tag{7}$$

Since the denominator of the objective function in (7) will be a constant for given P, it is sufficient to maximize R while satisfying the problem's constraints.

To determine the values of P_1 and P_2, we investigate proportional power allocation for maximizing R. Assuming that the BS will allocate a power for each user as proportional to the squared distance. Let's denote d_1 and d_2 ,the distance from the BS to U_1 and the distance from the BS to U_2 , respectively (i.e., $d_1 < d_2$).

We can define α, $0 < \alpha \leq 1$, as the partially allocated power from the total power P, i.e.,$P_1 = \alpha.P$ and $P_2 = (1 - \alpha).P$. Therefore, the power allocation fraction will be proportional to the squared distance for each user. Assuming $\alpha_1 \sim d_1^2$ and $\alpha_2 \sim d_2^2$.

Based on the fact that P_1 and P_2 follow an arbitrary binomial distribution, one can write $b(d_1^2, \alpha)$ and $b(d_2^2, \alpha)$ respectively, then P_1 follows an hypergeometric probability's law of parameters:P, $\frac{d_1^2}{d_1^2+d_2^2}$ and D, where D is the sum of squared distances $D = d_1^2+d_2^2$. Let's denote $G(P, \alpha_1, D)$ (Respectively $G(P, \alpha_2, D)$ for P_2)where the joint fractions would depend on distance as :

$$\alpha_1 = \frac{d_1^2}{d_1^2 + d_2^2} and \alpha_2 = \frac{d_2^2}{d_1^2 + d_2^2} \tag{8}$$

Thus, the values of P_1 and P_2 can be written respectively as:

$$P_1 = \frac{d_1^2.P}{D} and P_2 = \frac{d_2^2.P}{D} \tag{9}$$

Substituting the obtained values in (3) and (4) as we get the maximum R, then a maximum EE can be obtained.

IV. SIMULATION RESULTS

The energy performance of the proposed power allocation schema was evaluated through simulations having given the following results. In our simulation, the minimal distance between users and the BS is chosen 50 m. We set The total system bandwidth W, to be 1MHz and the total allocated power to the BS as 1W. The spectral power density of an AWGN,N_0 is -174 dBm/Hz.

Fig.1 shows the optimal Energy Efficiency EE versus total available power P . From that, it's obvious that EE increases when P increases. Once P has reached a certain threshold, EE endure unchanged, which means that regardless append additional power to the system, redundant power can't be used causing a EE's increase. When considering system performance with different levels of circuit power consumption, it's obvious that when circuit consumption is low, the performance in terms of EE will be better. For example, when $P = 0,4W$, a 1W increase of P_c causes an EE decrease from $4,1.10^6$ bits/Joule to $2,4.10^6$ bits/Joule.

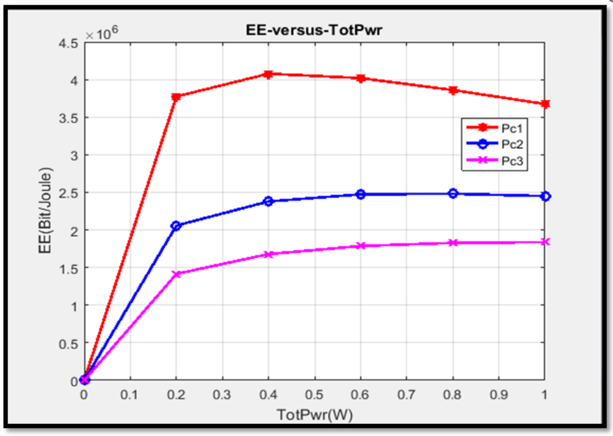

Fig. 1. Energy Efficiency EE versus Total Transmit Power P

To further clarify and compare the EE performance of our proposed NOMA allocation approach with that for conventional NOMA where the power allocation coefficient is fixed for the stronger near -user at $\alpha_1 = \frac{1}{5}$ and for the weaker cell-edge user at $\alpha_2 = \frac{4}{5}$ [7]. Thus, Their EE is plotted under the same conditions, for two users in a single subcarrier and circuit power consumption equal to 2W. Fig.2 indicates clearly an EE increase that shows better energy performance for our proposed allocation schema.

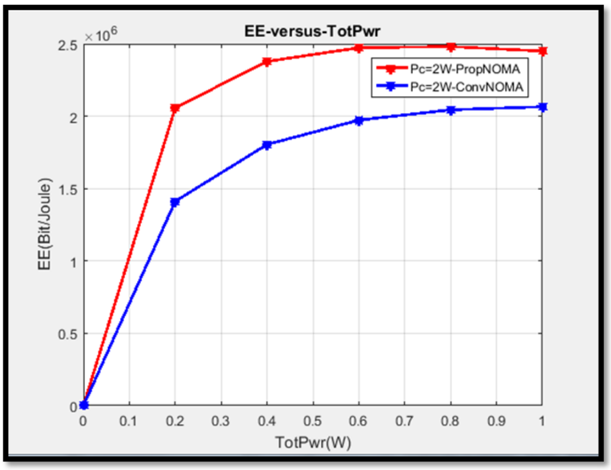

Fig. 2. EE versus P of proposal NOMA and conventional NOMA

V. Conclusion and Perspectives

In this paper, we focused on the power allocation problem for EE improvement for downlink NOMA systems. Optimum power values for each user have been obtained. The results of the simulation showed the effectiveness of the proposed allocation and the achievement of the expected energy performance objectives with a much lower complexity and a fast optimal solution. To clarify the improvement of the EE system, the proposed two-user power allocation strategy can easily be extended to the general case for NOMA transmission, where multiple users can be allocated to different subcarrier. This approach will be determinated in a future work.

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