Energy-Efficient Resource Allocation for NOMA Systems

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***Abstract*—As an aspiring multiple access scheme for future radio access, Non-Orthogonal Multiple Access (NOMA) is considered as a promising technique for the fifth-generation mobile communication networks (5G). The goal looks to improve Spectral Efficiency (SE) and flexible allocation of radio resources for users. In addition to this, Green Radio (GR), which focuses on Energy Efficiency (EE), is becoming a sought-after trend in the process of a future for an energy-efficient system. In this paper, added to SE improvement, we seek to enhance EE for downland NOMA systems. The problem is formulated as a non-convex optimization subject in which the basic idea is to maximize the EE by imposing a minimum satisfying SE while guaranteeing a Quality of Service (QoS) for each user. Optimization problem's solution is achieved when an optimal power allocation is obtained. Simulation results confirm analytical results and show the proposed power allocation scheme's efficiency to reach a flexible resources allocation.**

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

I. Introduction

The continuous explosive growth in traffic, the increasing proliferation of smart devices and the emergence of various application scenarios represent the main driving force behind the development of novel and new generations of Mobile Networks [1]-[3]. Recently, the fifth-generation mobile communication (5G) has spurred many research and development efforts.

Consequently, the astronomical growth in wireless access demand, as well as the corresponding exponential growth in infrastructure, has triggered a sharp increase in energy consumption, contributing to electromagnetic pollution and high operating costs. 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) [4]. However, the increase in traffic should not be at the expense of increased energy consumption. In this sense, research efforts continue to provide solutions, among which, Green Radio (GR) is proposed [5]. This option, named GR, focuses on Energy Efficiency (EE) as it will be indicated. This is addressed, in addition to Spectral Efficiency (SE), which had been studied as an effective solution. It is becoming a sought-after trend for future wireless network design [6]. Unfortunately, these items, named EE and SE, do not always coincide. Furthermore, a possibly conflict could arise [7]. So, how one could balance these two targets. This topic has received more attention and deserves to be deeply studied.

Motivated by the importance and the emerging challenges of energy saving and to meet the various strict constraints outlined above, efforts have not stopped finding solutions. For this, a smarter and more rational management of radio resources as well as a scalability of multiple access systems have been adopted.

Capacity scaling in 5G is enabled by a series of techniques and schemes such: cell densification, millimeter wave communication, new modulation, new coding schemes and advanced radio access [1]-[3]. Among these techniques, recently a more flexible multi-user access schemes have been studied. Research efforts have led to suggest a non orthogonal multiple access as it will be described. This is known as NOMA providing a potential multi users radio access scheme. This new technology stands out as a candidate for 5G [9]. It applies Superposition Coding (SC) to consider multiple user equipment's signals at the transmitter, and executes a Successive Interference Cancellation (SIC) at the receiver to separate and decode multi-user [8]-[9].

Various aspects of NOMA have been studied. Earlier performance evaluations for those systems could be used for both directions (downlink and uplink). Most problems in NOMA are usually due to practical power allocation and channel limitations [8]-[9]. Multiple approaches are adopted to address such issues in order to improve system performance's over Orthogonal Multiple Access , as well as other existing resource allocation schemes. This allows improving a satisfactory SE [10]-[12]. Added to this goal, EE is becoming a crucial performance measure and a trend in the process for an energy-efficient system [6]. The rational allocation of radio resources is considered one of the most effective ways to improve EE in NOMA [12]-[13]. Various resource allocation approaches are used in recent works to optimize EE and SE simultaneously [11]-[13].

Despite the existing literature, there is a lack of systematic approach to NOMA resource allocation from the point of view of mathematical optimization theory as well as a little problem complexity analysis. The aim is then to improve energy and spectral efficiencies in an easier manner. This problem is formulated as a non convex optimization subject

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in which the basic idea is to maximize EE and simultaneously minimize SE guaranteeing the Quality of Service (QoS). For this, a power allocation scheme is proposed. The given solution therefore makes it possible to achieve optimal power values. 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. A proposed power allocation approach is given in Section III. Section IV provides an evaluation of the energy performance of the proposed allocation approach through simulations. Finally, Section V concludes the paper and indicates perspectives.

II. SYSTEM MODEL

In order to maintain a relatively low receiver complexity, we consider a simple case where only two users are assigned on the same sub channel. A downlink NOMA system is considered where a single BS serves simultaneously users U_1 and U_2. This assumption is important because it also limits errors propagation. A fading channel is considered in the model. A perfect channel state information's knowledge is supposed to 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, we assume a superposition of the data symbols s_1 and s_2 of the user U_k , are thus coded in superposition with different transmission powers P_1 and P_2 on the same subcarrier, respectively. The signal transmitted by the corresponding BS is represented as:

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

Where the total transmit power is:P=P_1+P_2. The coefficient of the channel between the user U_k and the BS is written as $h_k = g_k.PL^{-1}(d_k)$, where g_k is the Rayleigh fading coefficient and $PL^{-1}(d)$ is the path loss function induced by distance d. It is also assumed that the BS and the users are equipped with a single antenna. The received signal by user U_k is written as follows:

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

The term w_k is an Additive White Gaussian Noise (AWGN) with a spectral power density N_0. We define, the equivalent channel gain of the user U_k as:$H_k = \frac{|h_k|^2}{N_0}$.

Let's assume the user U_1 is in the center of the cell with better channel quality. This will be referred to 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 principle, the BS will allocate more power to the weak user U_2 to ensure fairness and to facilitate the SIC process (further from the BS, more allocated power), i.e.$P_1 \leq P_2$. Thus, at the receiver, SIC is used to eliminate inter-user interference. The strong user U_1 can decode his own signal after removing the interference signal from U_2. It is assumed that U_1 can successfully decode the signal of the weak user without error propagation. Then, according to Shannon's capacity formula, the data rate of the strong user U_1 can be expressed as:

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

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

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

Then, the sum of the rate in NOMA system can be expressed as:

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

III. PROBLEM FORMULATION

In this section, we will formulate the optimization problem for the downlink NOMA system. EE and SE metrics are commonly defined as the ratio of data rate to power consumption and the ratio of data rate to total bandwidth respectively. The EE and SE metrics of the NOMA system are defined as:

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

$$SE = \frac{R}{W} \tag{7}$$

Where P is the total transmitted power and P_c is the constant power consumption of the circuits. The impact of the circuit power on the EE maximization will be discussed later for an energy optimization goal. The problem could be formulated as an optimization subject in which the basic objective is to maximize EE while requiring a minimum satisfaisant SE. Various resource allocation approaches are used in recent works to optimize EE and SE simultaneously [11]-[13]. In this paper, we propose a power allocation scheme to achieve the former defined objective. The Quality of Service (QoS) requirement for each user would be respected to ensure optimality. Since the resultant throughput R is a monotonic increasing function of P according to (5). Besides $\frac{dSE}{dP} > 0$, then requiring SE to be minimal can be equivalently understood as minimizing transmission power constraint $\overline{P}$ that satisfies $SE(\overline{P}) = \overline{SE}$. Let's denote $\overline{R} = \overline{SE}.W$ as the corresponding minimized wanted rate according to (7). The minimum data rate required by each user is taken into account. Thus, maximizing EE requires a minimum transmitted power and minimum overall data rate R^{min} , guaranteeing a wanted QoS. Such goal could be formulated as:

$$\begin{aligned} MaxEE &= \frac{R}{P + P_c} \\ C1 &: 0 \leq P \leq P^{max} \\ C2 &: R_k \geq R_k^{min}, k = 1, 2 \\ C3 &: P_1 \leq P_2 \end{aligned} \tag{8}$$

Where: R_k^{min} the minimum data rate of the user U_k, $P = P_1 + P_2$, is the total transmit power.Constraint $C1$ imposes the maximum available transmit power at the BS, P^{max}. $C2$ guarantees the minimum data rate constraints for the programmed users determined by requiring the QoS, The constraint C3 indicates successful SIC decoding.

Due to the minimum data rate constraints specified in (8) and the fact that R is an increasing function of P , the minimum transmission power must be large enough to simultaneously satisfy the minimum data rate requirements of two users. In the remainder of this paper, we will always assume $P^{max} \geq \overline{P}$.
To optimize the problem appropriately, maximizing EE while satisfying SE constraint, must be considered separately. Before focusing on the problem of maximizing EE, consideration is given, firstly, to required SE. For this, a minimum transmitted power $\overline{P}$ and a minimum overall data rate R^{min} are required. In particular, we assume that users have same minimum data rate, i.e. $R_1^{min} = R_2^{min} = R^{min}$.
According to (3) and the constraint $C2$ in (8), we have:

$$P_1 \geq \frac{A}{H1} and P_2 \leq \frac{H_1 P - A}{H_1} \tag{9}$$

Where: $A = 2^{\frac{R^{min}}{W}} - 1$
Furthermore, we define: $P_1^1 = \frac{A}{H_1}$ and $P_2^1 = \frac{H_1 P - A}{H_1}$
According to (4) and the constraint $C2$ in (8), we have:

$$P_2 \geq \frac{A(1 + H_2 P)}{(A+1)H_2} and P_1 \leq \frac{H_2 P_2 - A}{H_1 + H_2} \tag{10}$$

Furthermore, we define:$P_1^2 = \frac{H_2 P_2 - A}{H_1 + H_2}$ and $P_2^2 = \frac{A(1+H_2 P)}{(A+1)H_2}$
(9) and (10)give $\overline{P_1}$ formulated with the condition $P_1^1 = P_1^2$ such:

$$\overline{P_1} = \frac{H_1 H_2 P - A(2H_1 + H_2)H_2}{H_1 H_2} \tag{11}$$

From (9) and (10),$\overline{P}$ can be formulated with the condition $P_2^1 = P_2^2$ as:

$$\overline{P} = \frac{AH_1 + A(1+A)H_2}{H_1 H_2} \tag{12}$$

When $P \geq \overline{P}$, we have $P_1 \leq P_2$. In particular, when $P = \overline{P}$, it can be seen that the data rates of the user U_1 and U_2 correspond to R^{min}. After this formulation, we will proceed to the second step and we will focus on the maximization of EE. Then, the optimization problem (8) can be equivalently written as:

$$\begin{gathered} Max EE = \frac{R}{P + P_c} \\ C1 : P \geq \overline{P}, P = P_1 + P_2 \\ C2 : R_k \geq R_k^{min}, k = 1, 2 \end{gathered} \tag{13}$$

Based on the non-convexity of the objective function as well as that of the constraints, it is obvious that the problem (13) will have a non-convex feature. Since the denominator of the objective function in (13) will be a constant for given P , it is sufficient then, to maximize EE, maximizing R.
We assume that $H_1 > H_2$ and $P \geq \overline{P}$:
$E = \frac{H_2 P - A_2}{(1+A_2)H_2}$ where $A_k = 2^{\frac{R_k^{min}}{W}} - 1$ for k=1,2. The optimal solution of the optimization problem (13) is obtained as:
$P_1^* = E$ and $P_2^* = P - P_1^*$
Proof:
Since $P_2 = P - P_1$, $P_1 \leq P_2$ is equivalent to $P_1 \leq \frac{P}{2}$ and the objective function becomes:

$$R(P_1) = W[log_2(1 + H_1 P_1) + log_2(\frac{1 + H_2(P - P_1)}{1 + H_2 P_1})] \tag{14}$$

for $H_1 > H_2$ we evaluate the first derivative of $R(P_1)$ and we obtain:

$$\frac{dR}{dP_1} = W[\frac{H_1}{1 + H_1 P_1} - \frac{H_2}{1 + H_2 P_1}] \geq 0 \tag{15}$$

This implies that $R(P_1)$ is not decreasing. The maximum is reached at the upper limit of P_1. Consider the constraint $R_1 \geq R_1^{min}$ and $R_2 \geq R_2^{min}$, gives:
$\frac{A_1}{H_1} \leq P_1 \leq E$ which stands if and only if $\frac{A_1}{H_1} \leq E$, i.e : $P > \overline{P}$.
Finally,$P_1 = E \leq \frac{P}{2}$ is true . The optimal solution will be $P_1^* = E$

IV. SIMULATION RESULTS

In this section, the performance of the proposed resource allocation strategy for the NOMA system was evaluated through simulations that have given the following results in the following conditions: the bandwidth of the system is 1 MHz. Users are randomly generated and uniformly distributed in the cell. The minimum distance between users is 20 m and the minimum distance between users and BS is 50 m. It was also assumed that each coefficient of the channel follows an identical and independent Gaussian distribution (i.i.d.) written as $g_k \sim CN(0, 1)$ for k=1,2 and an exponent of path loss is set to 3. The spectral power density of the AWGN N_0 is -174 dBm/Hz. To ensure the QoS for each user, the minimum data rate requirements are introduced.
Fig.1 shows the optimal Energy Efficiency EE versus total transmit power P . From that figure we see that EE increases with increasing. Once P has reached a certain threshold, EE begins to decline, which means that regardless of how much additional power is added to the system, redundant power can't be used causing EE's increase. When considering system performance with different levels of circuit power consumption, it is obvious that when circuit consumption is low, the performance in terms of EE will be better. For example, when P = 15dBm, a 1W increase of P_c causes an EE decrease from $2, 8.10^7$ bits/Joule to $1, 4.10^7$ bits/Joule.

Fig.2 shows an achievable EE versus P performance's of our proposed NOMA allocation strategy compared with that of conventional OFDMA [10]. Thus, their EE is plotted under the same conditions, for two users in a single subcarrier and a 1W circuit power consumption. From the figure, it's obvious that NOMA with propsed power allocation performs significantly better than OFDMA as it achieves higher EE.

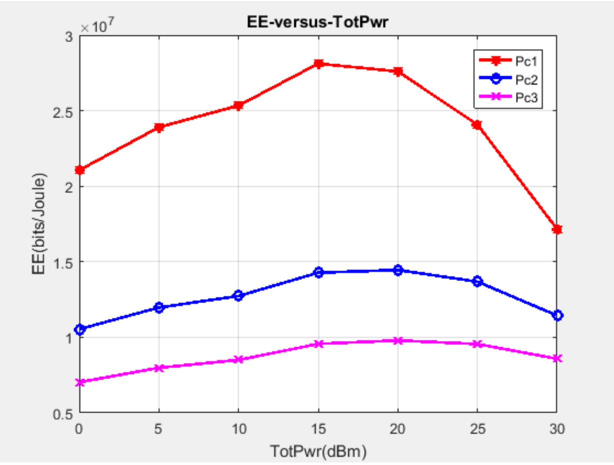

Fig. 1. Energy Efficiency EE versus Total Transmit Power P

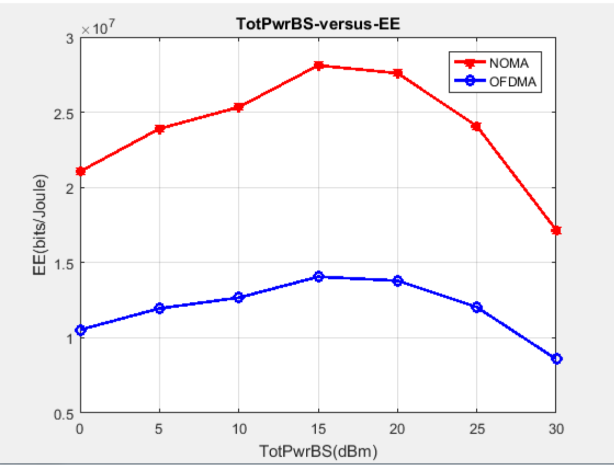

Fig. 2. EE versus P of proposal NOMA and conventional OFDMA

V. CONCLUSION AND PERSPECTIVES

In this paper, we have focused our attention on resource allocation problem in downlink NOMA systems. The problem has been formulated as an optimization subject in which the basic idea is to maximize the EE within the framework of requiring a satisfying minimum SE with respect of a guaranteed QoS. An optimal power allocation scheme and an optimal transmission power value have been obtained. Simulation results show the effectiveness of the proposed allocation scheme and the achievement of the expected performance objectives with a much lower complexity and a fast optimal solution. To clarify the EE improvement, the proposed two-user power allocation method can easily be extended to the general multiuser case, where users can share different subcarriers for NOMA transmission. This approach will be done in a future work.

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