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Power Allocation Optimization in NOMA System for User Fairness in 5G Networks

Chekwas Ifeanyi Chikezie
Dept. of Telecommunications Engineering
Federal Univerisity of Technology,
Minna, Niger State, Nigeria.
chekwas.pg2010285@st.futminna.edu.ng

Michael David
Dept. of Telecommunications Engineering
Federal Univerisity of Technology,
Minna, Niger State, Nigeria.
mikeforheaven@futminna.edu.ng

Abraham Usman Usman
Dept. of Telecommunications Engineering
Federal Univerisity of Technology,
Minna, Niger State, Nigeria.
usman.abraham@futminna.edu.ng

Abstract—Non-orthogonal multiple access (NOMA) has been presented as an alternative technology due to its ability to accommodate immense connectivity and enhances spectral efficiency in 5G and future wireless networks. NOMA, in contrast to orthogonal systems, allows numerous users to share the same radio resource at the same time, breaking the orthogonality of traditional multiple access. However, power allocation is a critical challenge in designing an effective NOMA system. In this work, the authors investigated fair power allocation and considered it pertinent to improve the scheme further. To ensure user fairness, we proposed an improved fair power algorithm that can be modified dynamically based on target rate requirements and channel state information. The simulation results show that the proposed improved fair power allocation performs better than other traditional schemes.

Keywords—NOMA, Power allocation, Target Rate, User fairness

I. INTRODUCTION

Non-orthogonal multiple access (NOMA) is a promising technology for 5G and future wireless networks that boost spectral efficiency and allow massive connections [1],[2]. The main concept of NOMA is to break the orthogonality of conventional multiple access by allowing multiple users to share the same radio resource simultaneously. NOMA improves the system's spectral and energy efficiency while supporting more users [3]. Despite NOMA's advantages, the performance of the NOMA is heavily dependent on the power allocation and decoding order within the users. Power allocation should be optimized to ensure acceptable performance and fairness among NOMA users[4],[5]. Power allocation influences the system's performance, such as interference control and user rate distribution. If the power allocation is not properly done, it will result in an unfair rate distribution and outage. In this circumstance, the power allocation of users becomes a critical consideration in the design of a NOMA system. Therefore, in this study, the user rate distribution of the NOMA system is maximized by optimizing the power allocation algorithm.

Various power allocation algorithms have been proposed in previous studies to actualize user fairness for efficient communications. Although it was not ideal, the authors in [6] proposed a dynamic fractional transmission power allocation. There are no specified optimization goals in this scheme. A brute force search of all possible pairs of User Equipment and various fractions of power allotted to them are used to find the best power allocation. This, however, is highly complicated and impractical. Since NOMA multiplexes users in the power domain, transmit power must be divided among them. As a result, the power given to one user impacts the power given to the other. The authors in [7] proposed full Search Power Allocation. This technique can only be implemented by searching for all possible user pairs. Full Search Power Allocation is computationally challenging, but it also increases the signaling overhead of SIC decoding order and power allocation ratios. As an alternative to the Full Search Power Allocation, users could be divided into different user groups depending on their channel gains using pre-defined thresholds. The user grouping might be pre-defined or have a fixed power allocation per group.

A Fixed power allocation algorithm was proposed in [8]; this scheme optimizes the power allocation of a NOMA system by allocating fixed or static values of transmitting power to the users. A user with low channel gain is given more power in fixed power allocation, whereas a user with strong channel gain is given less power. The fixed power allocation scheme is the simplest algorithm as it can greatly minimize the communication overhead between the base station and the user equipment. The main flaw of the fixed power allocation scheme is that it lacks a defined algorithm for determining how much power should be provided to various users depending on their channel gain. Fixed power allocation is deemed inefficient since power levels are set without considering the channel condition. In [9], the authors proposed a fair low-complexity and suboptimal power allocation scheme. Unlike the fixed power allocation, the power allocation coefficients are adjusted dynamically with respect to target rate requirement and channel state information. The main flaw of fair power allocation is that the outage probability of the far user increases in lockstep with the target rate requirement. The chances of a far user obtaining the target rate decreases as the target rate increases. In the fair power allocation, the far user is given more power. This would increase the probability of an outage. To this end, we propose to improve the fair power allocation scheme to ensure fair rate distribution and minimize the outage probability of both the far and near users in a NOMA system.

II. BASIC PRINCIPLES OF POWER ALLOCATION

NOMA power allocation can be performed in various ways, considering the distance from the transmitter, channel gain, fairness index, signal-to-noise ratio, or energy efficiency as a criterion. Implementing an effective power allocation algorithm will result in a near-perfect successive interference cancellation at the transmitter [10]. NOMA superimposes codes of several users sharing the same resource at the transmitter and applies successive interference cancellations at the receiver to decode the user's signal [11]. This is the fundamental premise of successive interference cancellation (SIC).

III. SIGNAL MODEL

A two-user downlink transmission scenario from a base station is considered. Where α_n and α_f are the power allocation coefficients $(\alpha_n + \alpha_f = 1)$.

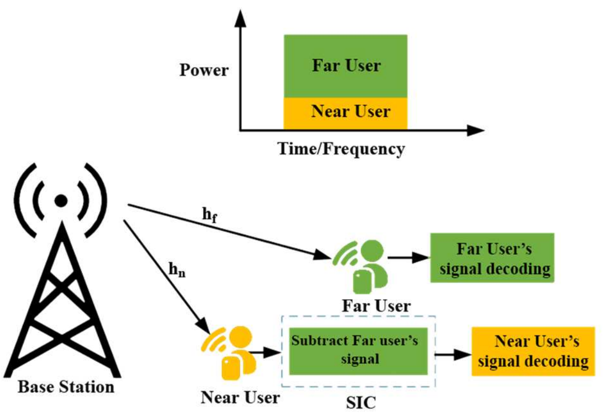

Figure 1 NOMA downlink transmission

In NOMA, the weak user receives more transmission power. By considering other users' messages as noise, the weak user can detect its message.[12] The near user with the stronger channel condition, on the other hand, will first detect its message partner, then subtracts the far user's message, and lastly decode its message. This process is called successive interference cancellation.

A. NOMA CAPACITY

The following are the capacity formulae for NOMA far and near users [13] :

$$R_f = \log_2\left(1 + \frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2}\right) \tag{1}$$

$$R_n = \log_2\left(1 + \frac{|h_n|^2 P\alpha_n}{\sigma^2}\right) \tag{2}$$

α_n is the near user's coefficient for power allocation

α_f is the far user's coefficient for power allocation

h_n is the near user's coefficient for Rayleigh fading channel

h_f is the fear user's coefficient for Rayleigh fading channel

P is the total transmit power

σ^2 is the Noise power

B. FAIR POWER ALLOCATION COEFFICIENTS α_n and α_f

The aim is to choose between α_n and α_f in such a way that $R_f = R^*$. Let R^* be the far user's target rate.

$$\log_2\left(1 + \frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2}\right) = R^* \tag{3}$$

$$\frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2} + 1 = 2^{R^*} \tag{4}$$

$$\frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2} = 2^{R^*} - 1 \tag{5}$$

Let $\xi = 2^{R^*} - 1$

$$\frac{|h_f|^2 P\alpha_f}{|h_f|^2 P\alpha_n + \sigma^2} = \xi \tag{6}$$

$$|h_f|^2 P\alpha_f = \xi|h_f|^2 P\alpha_n + \xi\sigma^2 \tag{7}$$

Since

$$\alpha_n + \alpha_f = 1,$$

$$|h_f|^2 P\alpha_f = \xi|h_f|^2 P(1 - \alpha_f) + \xi\sigma^2 \tag{8}$$

$$|h_f|^2 P\alpha_f = \xi|h_f|^2 P - \xi|h_f|^2 P\alpha_f + \xi\sigma^2 \tag{9}$$

collect all the α_f terms to the LHS,

$$|h_f|^2 P\alpha_f + \xi|h_f|^2 P\alpha_f = \xi|h_f|^2 h_f|^2 P + \xi\sigma^2 \tag{10}$$

$$\alpha_f|h_f|^2 P(1 + \xi) = \xi(|h_f|^2 P + \sigma^2) \tag{11}$$

$$\alpha_f = \frac{\xi(|h_f|^2 P + \sigma^2)}{|h_f|^2 P(1 + \xi)} \tag{12}$$

after computing α_f, α_n can be written as

$$\alpha_n = 1 - \alpha_f \tag{13}$$

C. PROPOSED IMPROVED FAIR POWER ALLOCATION

One of the problems with the fair power allocation is that when the limiting operation was executed, the far-user had a weak channel from equation (12)., and whenever α_f is greater than 1, α_f is set to 1. By setting $\alpha_f = 1$, α_n will be automatically set to 0, which sets the near user on outage since no power was allocated to him. This was the motivation for enhancing the fair power allocation scheme.

To enhance the fair power allocation, instead of limiting α_f to 1, α_f was set to 0. Which automatically sets $\alpha_n = 1$. Setting $\alpha_f = 0$ does not affect the far user since it can't get out of outage by setting $\alpha_f = 1$ (allocating him the entire power).

Comparison of Theoretical and Simulations Results

1) Fixed power allocation:

Users' power allocation factors are constant in fixed power allocation because power is allocated based on a set of values. The fixed power allocation prioritizes the user with the lower channel gain [13].

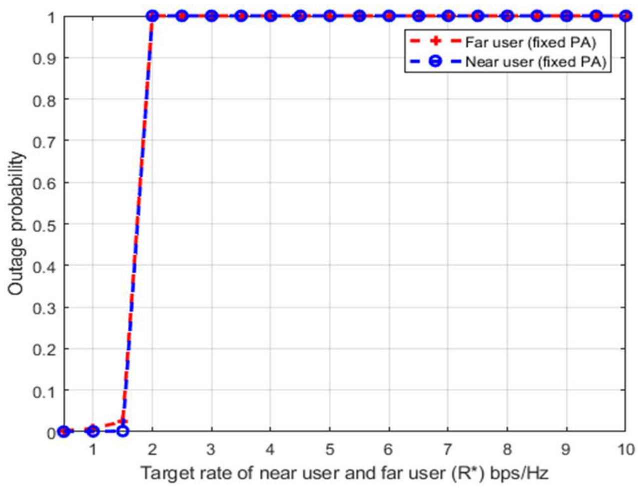

Figure 2 Outage probability vs R* for fixed Power allocation

This scheme doesn't perform too well when the target rate (R*) approaches 1.5 bps/Hz, and the outage probability will always fall to 1. The target rate requirement and channel state information are not utilized in fixed power allocation. This scheme is not ideal though it's easy to implement.

2) Fair power allocation:

The fair power allocation coefficients α_n and α_f can be adjusted dynamically with respect to target rate requirement and channel state information.

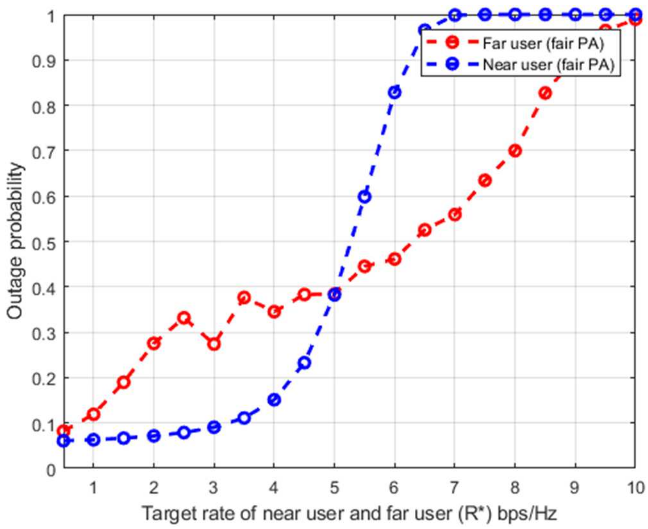

Figure 3 Outage Probability vs R* for fair Power allocation

The far user's outage probability increases in lockstep with the target rate requirement in fair power allocation. The chances of a far user obtaining the target rate decreases as the target rate increases. This would increase the probability of an outage. The near user's outage is fairly sharp around the target rate of 4 to 7 bps/Hz. Any value above this, the near user will experience a continuous outage; however, this scheme is preferable to fixed power allocation.

3) Proposed improved fair power allocation:

Compared to the fair power allocation, the proposed improved fair power allocation has a lower outage probability and can be modified dynamically depending on target rate requirements and channel state information. Whenever α_f exceeds 1, Instead of limiting $\alpha_f = 1$, α_f is set 0, which automatically sets $\alpha_n = 1$. When $\alpha_f = 0$, it does not affect the far user's outage since setting $\alpha_f = 1$ can't get it out of outage.

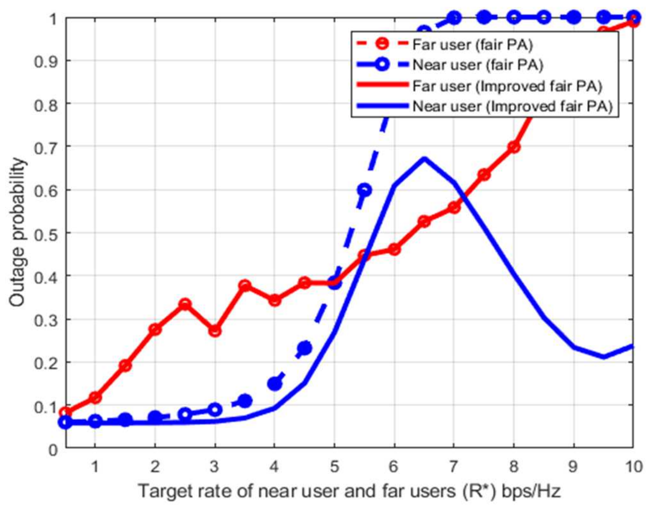

Figure 4 Outage Probability vs R* for the proposed improved fair Power allocation

The outage pattern of the far user is depicted in figure 3. This indicates that setting $\alpha_f = 0$, will not affect the far user's outage. The probability of an outage for a near user rises, peaks, and then steadily declines.

When, R^* is between 0 and 6.5 bps/Hz, more power was allocated to the far user at the expense of the near user's performance. Any value more than 6.5 bps/Hz, may not entirely satisfy the target rate. Rather than allocating all power to the far user, priority is given to the near user. This reduces the near user's outage for a target rate above 1.5 bps/Hz while having no effect on the far user's outage.

D. CONCLUSION

Aiming to further enhance the system efficiency and quality of service, especially at the cell edge in the future radio access network, we investigated the power allocation schemes in NOMA for next-generation wireless networks. This study proposes an improved fair power allocation scheme. The simulation results show that improved fair power allocation performs well for a Rayleigh fading channel than other state-of-art power allocation schemes. Future research can be carried out for different channel models of a NOMA system.

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