Fair Power Allocation for OFDM based NOMA

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***Abstract*—This study aims to replicate and extend the results of a previous study on non-orthogonal multiple access (NOMA) for orthogonal frequency-division multiplexing (OFDM) systems. The original study proposed a proposed a power domain NOMA approach to improve system performance and achieve fairness in multi-user OFDM-NOMA systems. The aim of this current study was to replicate the results of the previous study through simulations in MATLAB and expand on the original findings by scaling up the experiments to include four or more users.**

The main contribution of this study is its potential to enhance the understanding and implementation of NOMA for OFDM systems inspired by multinumerology concepts. The comparison between the simulation results obtained in this study and those obtained in the original study will help assess the accuracy of the replication and highlight any differences or discrepancies that may exist. The results of this study can be used to inform the design and optimization of NOMA-based OFDM systems for future applications in various domains such as wireless communication, mobile networks, and the Internet of Things.

***Index Terms*—NOMA, OFDM, Multinumerology**

I. Introduction

In recent years, Non-Orthogonal Multiple Access (NOMA) has emerged as a promising technology to address the increasing demand for high data rates and connectivity in wireless networks. NOMA allows multiple users to share the same time and frequency resources simultaneously by assigning different power levels and signature sequences to their signals. This technology offers several advantages over conventional orthogonal multiple access (OMA) techniques, such as improved spectral efficiency, higher throughput, and better fairness. This can be understood clearly from the below image.

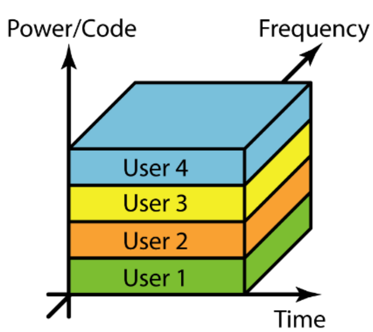

Fig. 1. Basic arcitecture of NOMA

However, efficient power allocation is a highly critical issue in NOMA systems, especially when the channel conditions of different users are similar. In such scenarios, traditional power allocation schemes may not be effective in maximizing the system's overall throughput and fairness. In particular, allocating equal power to all users can result in poor performance, especially for users with poor channel conditions. And hence the given transmission may not achieve capacity in terms of rates.

To address the challenges of power allocation in NOMA systems, various techniques have been proposed in the literature. However, some commonly used approaches, such as the water-filling algorithm, is not really effective in practice, particularly when the channel conditions of different users are similar. In such scenarios, allocating power levels solely based on the channel gains of users can lead to suboptimal performance.

So power allocation in NOMA systems remains an active area of research. In particular, the power allocation problem becomes more complex in systems with multiple numerologies and multiple users. Hence, in this study, we aim to replicate the results of a recent research article [1] on NOMA for Multinumerology OFDM Systems and extend its findings by scaling up the experiments for four users. The simulation results of our study can provide insights into the performance of NOMA in such systems and contribute to the development of more efficient power allocation schemes. We also refer to this [2] for existing and efficient power allocation algorithms.

II. Works of Base Paper

A. Methodology Used

This paper suggested an OFDM based approach for NOMA, which takes advantage of numerology to alleviate limitations that come with traditional NOMA methods. Essentially, this involves using varying subcarrier spacings, namely wide and narrow subcarriers for different users. The paper focuses on a three-user scenario with two uses having similar channel conditions.

In conventional NOMA systems, users share the same subcarriers with different power allocations which enables SIC to work efficiently. But in this paper, one of the users is allocated a narrow subcarrier which is less frequently spaced in frequency and rest two users are allocated the wide subcarrier. This allocation separates the users having similar channel conditions into different subcarriers so that we can perform SIC at the receiver. Following is the illustration of the same.

It is clear from the above diagram that the zero crossings of wide subcarriers fully overlap within the same wide subcarriers and make a zero crossing at the peaks of the other wide

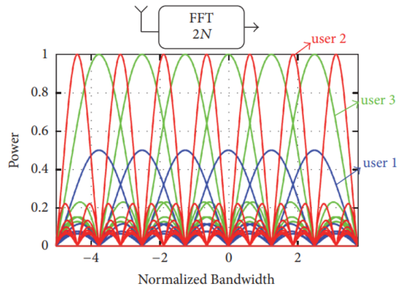

Fig. 2. Different carrier spacings for users

subcarriers. Further, the narrow subcarriers do not impose any interference with the peaks of wide subcarriers and vice-versa. Eventhough the narrow subcarriers share some bandwidth with wide subcarriers, the detection of wide subcarrier users is independent of narrow ones and therefore SIC can be applied purely based on power differences.

By assigning one of the users to narrow subcarriers, the amount of Co-Channel interference with wide subcarrier is reduced, and the residual interference with wide subcarrier on narrow one can be eliminated easily by the SIC process which enhances BER of the system.

Below is the corresponding time domain representation of signal at the transmitter's end.

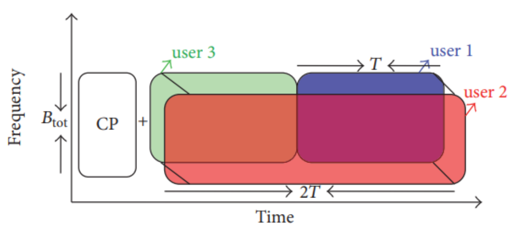

Fig. 3. Time representation for proposed NOMA at the TX end

B. Problem Description

The paper describes a three user scenario wherein one user is closer to the base station than the other two and the other two users have same channel conditions. Below is an image for the same.

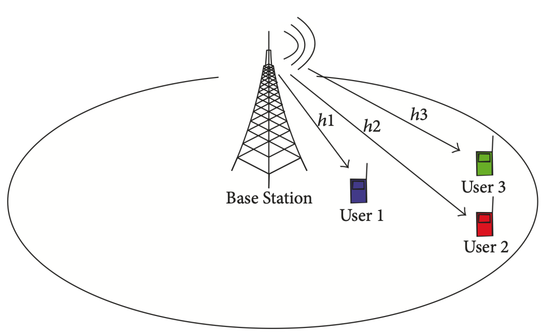

Fig. 4. Simulation for 3 users

So according to the proposed scheme, User 1 and User 3 are allocated wide subcarriers and User 2 is allocated narrow subcarrier. Thus the SIC process becomes easier as it has to differentiate only two users in one of the frequency bands. This achieves better user fairness as User 2 and User 3 cannot be paired together in the same subcarrier.

C. Signal Representation and Analysis

An OFDM transmission symbol for User i on a wide subcarrier can be obtained by taking N-point IFFT on the modulated signal in the frequency domain. Mathematically, we can write the time domain signal as follows-

$$x_{w_i}(n) = \frac{1}{N}\sqrt{P\alpha_i}\sum_{k=0}^{N-1} X_{w_i}(k).e^{\frac{j2\pi nk}{N}}$$

For the narrow subcarrier, we first interpolate the signal in frequency domain by making all even indices 0 and filling the modulated data in odd indices. The corresponding representation in time domain is as follows-

$$x_{n_i}(n) = \frac{1}{2N}\sqrt{P\beta_i}\sum_{k=0}^{2N-1} \hat{X}_{n_i}(k).e^{\frac{j2\pi nk}{2N}}$$

with $\hat{X}_{n_i}$ as

$$\hat{X}_{n_i} = \begin{cases} X_{n_i}(\frac{l-1}{2}) & ;\ l = 1, 3, 5, \ldots, 2N-1 \\ 0 & ;\ otherwise \end{cases}$$

From the property of periodicity of FFT, the narrow band signal in time domain can be re-written as

$$x_{nr}(n+N) = -x_{nr}(n)$$

Thus the second half of signal x_{nr} is just a reversed copy of the first half because of odd subcarriers usage. Thus the transmitted signal in time domain can be written as-

$$s(r) = \begin{cases} x_{w_1}(r) + x_{nr_1}(r), & 0 < r < N-1 \\ x_{w_2}(r) - x_{nr_1}(r), & N \leq r < 2N \end{cases}$$

After this, we add channel prefix to avoid inter-symbol interference.

At the receivers end, we first take an 2N-point IFFT after channel equalization and removing channel prefix. Now to compute the output on both odd and even subcarriers, we can take f = Qk + q to downsample the IFFT of the receieved signal. Then the received signal can be represented as follows-

$$S(Qk+q) = \sum_{r=0}^{N-1}(x_{w_1}(r) + x_{nr}(r))e^{\frac{-j2(Qk+q)}{QN}} + \sum_{r=N}^{2N-1}(x_{w_2}(r) - x_{nr}(r))e^{\frac{-j2(Qk+q)}{QN}}$$

For this case, Q = 2. To obtain the wide subcarrier output, we can set q = 0 which results in sampling out the even samples in the received signal. The resulting signal on the even subcarriers is

$$S(2k) = \sqrt{P\alpha_1} X_{w_1}(k) + \sqrt{P\alpha_2} X_{w_2}(k)$$

We can clearly recover User 1 and User 3's signal via SIC at their respective users as the narrow subcarriers are absent. To decode the narrow subcarrier user's signal, the wide subcarrier signals can be reconstructed, then subtracted with received signal after remodulation.

The tranciever block diagram is given below.

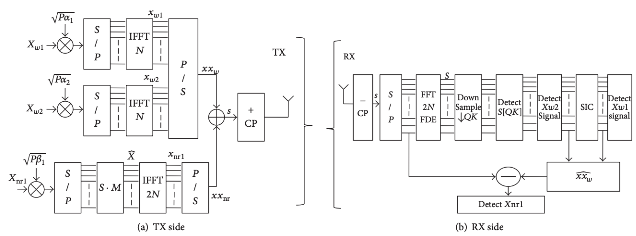

Fig. 5. Tranciever design for proposed NOMA system

D. Simulations

We replicated the results of this paper by simulating in matlab and tried different power allocations to verify that the given power coefficients acieved optimal performance in terms of capacity. The BER vs SNR plot obtained was as follows-

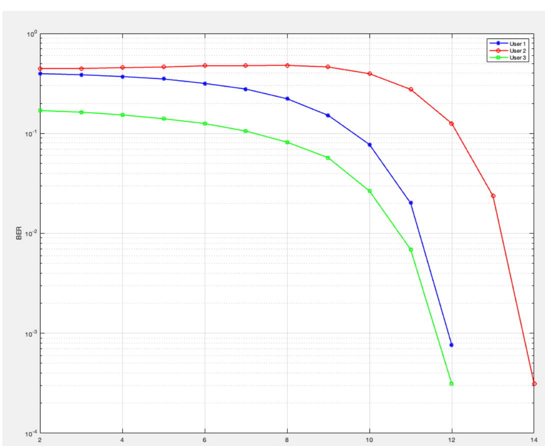

Fig. 6. BER vs SNR plot for three user case

III. Scaling this method

We are now interested in trying to make this method scalable to multiplex more number of users. Consider the four user case where two users have the same channel conditions as contrast to the above case with 3 users. In this case, we multiplex two users on the wide subcarrier and two on narrow subcarrier such that neither of the two users in both narrow and wide subcarriers have similar channel conditions.

We then perform the same multiplexing, transmitting, demodulating and downsampling schemes as proposed in the above paper. From the power allocation point of view, we tried fractional power transmission, water-filling algorithm and manual power allocation to find out the best scheme. The BER vs SNR plots are attached below-

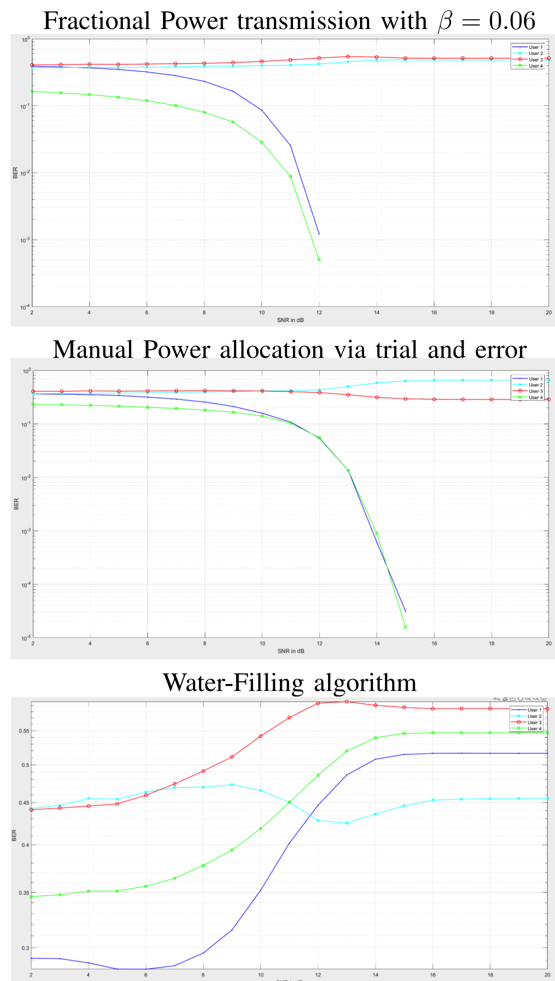

Fig. 7. BER vs SNR for various primitive power allocation schemes

IV. Power Allocation algorithms

A few algorithms that could be explored further for optimal power allocations are listed below with their brief descriptions. We referred to this paper [2] for information.

A. Optimal Power Allocation

The Optimal Power Allocation scheme aims to maximize the overall system throughput and sum rate while maintaining a certain level of fairness. To do this, the power matrix is initialized with all possible values and a target fairness index is set. Then, for every combination of power allocation, fairness index, and capacity, the capacity is calculated. If the fairness index is less than the target value, the capacity is set to zero. The maximum capacity is initially set to zero and is updated every time a calculated capacity value is greater than the current maximum capacity.

$$MaxSumCapacity = \sum_{i=1}^{n} BW \times \log_2\left(1 + \frac{P_i \times |h_i|^2}{N + \sum_{k=1}^{i-1} P_k \times |h_k|^2}\right)$$

The sum capacity is evaluated using a formula that takes into account the power levels and channel gains of each user. The fairness index is calculated based on the sum capacity and the individual capacities of each user. The scheme is found to perform better than conventional Orthogonal Multiple Access (OMA) in terms of throughput. However, as the fairness index is increased, the sum capacity decreases, and there is no significant difference in performance between OMA and Non-Orthogonal Multiple Access (NOMA).

The Optimal Power Allocation scheme uses an exhaustive search to provide the best performance under a fairness constraint.

B. Particle Swarm Optimization (PSO)

It works by optimizing the power allocation in NOMA by randomly initializing a large number of particles and moving them through a search space until an optimal solution is found. The algorithm takes in the population size and channel gain as inputs and updates the particles' velocities and positions to maximize the energy efficiency of the system, which is the ratio of data rate to transmission power. The fitness function (formula shown below) is used to enforce the optimization problem's constraints. PSO is faster and finds the global optimum, making it an optimal PA scheme for achieving high energy efficiency. However, it requires careful initialization of various parameters such as swarm size, number of iterations, particle velocity, and correction factor. PSO yields optimal power allocation coefficients based on the number of subcarriers and channel gain of each user, but it is an iterative and time-consuming procedure.

The fitness function for Particle Swarm Optimization can be defined as follows-

$$f = \sum_{s=1}^{S} \log_2\left(1 + \frac{h_s^2 P_s}{\frac{B}{S} N_0}\right) - 100 * \max\left(0, \sum_{s=1}^{S} (P_s - P_{\max})^2\right)$$

V. Further Investigations

We could try out the above power allocation schemes to optimize the performance of this system. Also if we want to multiplex more number of users, we can generate more narrow subcarriers with lesser spacings and each of them can be allocated to an user having similar channel and rest others to wide subcarrier which will be multiplexed using NOMA scheme.

Essentially we have shown that we can generate multiple subcarriers and allocate them to different users which is OFDM and multiplex multiple users in the same subcarrier by alloting different power bands which is NOMA.

Unfortunately, we didn't have much time to implement the above strategies but theoretically the above methods look promising. Kindly consider our apology for the same for not being able to implement the above methods successfully on time.

VI. Conclusion

In conclusion, this study aimed to investigate the effectiveness of different power allocation techniques in NOMA systems with multiple numerologies and multiple users. The simulation results indicate that conventional OMA schemes can lead to significant performance degradation in such scenarios. Therefore, effective power allocation techniques are necessary to improve the system's throughput and fairness.

In this study, we compared several power allocation techniques, and the simulation results showed that the proposed NOMA scheme achieved higher throughput and better fairness compared to conventional OMA schemes.

The findings suggest that power allocation in NOMA systems with multiple numerologies and multiple users is a challenging problem, and effective power allocation techniques are necessary to improve the system's performance. Future research can investigate the effectiveness of other game theory-based techniques or machine learning-based approaches in such scenarios.

In summary, this study highlights the importance of effective power allocation in NOMA systems and presents insights into the performance of different power allocation techniques. The findings can contribute to the development of practical and efficient NOMA systems and enhance the understanding of power allocation in wireless communication systems.

VII. Acknowledgment

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