SCHOOL OF ELECTRICAL ENGINEERING AND
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NOMA for 5G Wireless Communication Systems

by

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Abstract

Non-orthogonal multiple access (NOMA) as one of the upcoming and promising multiple access technologies has a significant impact on the development of the 5G wireless communication systems, which states in [1]- [25]. In this report, a literature review on the NOMA related works of 5G communication network is presented. A systematic approach to analyze the differences between NOMA and OMA is provided as well. A detailed description of downlink system model is illustrated by using mathematical equations. The resource allocation design, i.e., user pairing and power allocation, is formulated as a non-convex optimization problem. In general, there is no systematic approaches for solving this kind of problems efficiently. As a result, low computational complexity resource allocation is designed. Specifically, a user pairing scheme, namely user data rate requirement-based selection scheme, is proposed as a suboptimal solution to solve the resource allocation problem. This proposed algorithm, which takes into account user channel condition, user data rate requirement and the maximum transmit power constraints, is described in detail. Besides, simulation is performed to illustrate the system performance of the proposed algorithm. Furthermore, we have discussed in the aspect of average system throughput, weak user's achievable data rate and multiuser diversity. The future work is included at the end of this thesis.

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Abbreviations

The abbreviation used in this report as shown below:

NOMA	Non-Orthogonal Multiple Access
OMA	Orthogonal Multiple Access
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
5G	Fifth-generation
4G	Fourth-generation
3G	Third-generation
2G	Second-generation
IoT	Internet-of-Things
QoS	Quality-of-Service
SIC	Successive Interference Cancellation
CCI	Co-channel Interference
BS	Base Station
SINR	Signal-to-Noise-plus-Interference Ratio
KKT	Karush-Kuhn-Tucker
MIMO	Multiple-input multiple-output

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I. Introduction

Nowadays, with the fast growth of mobile internet and rapid development of the Internet-of-Things (IoT), according to [1], [2] and [3], multiple requirements in 5G networks that needed to be perfectly fulfilled are in the aspects of enhancing mobile broadband, mission critical service, and massive IoT. To meet the demand of enlarging mobile broadband, extreme capacity is expected to be 10 Tbps per km^2, and extreme data rate is expected to reach to Multi-Gigabits per second. In other words, high spectral efficiency should be achieved so that 5G networks are able to handle explosive data traffic. For mission critical control, ultra-low latency needs to be as low as 1 millisecond. Since one of the basic requirements for the next-generation wireless communication system is to support massive IoT devices, it requires the 5G network to be capable of severing users or/and devices that used in challenging locations, refers to [1]- [6], [9] [15], [22], [23], [30], [31] and [40].

In practice, various multiple access scheme has been implemented in various wireless communication systems for different applications. As [4] stated, the aim of multiple access schemes is to serve multiple users by using limited bandwidth and power resources. In the history of wireless communication systems, the first generation (1G) used FDMA as its multiple access scheme, and the multiple access scheme for second generation (2G) was mainly TDMA. As for the 3G and 4G networks, CDMA was applied for 3G communication systems. OFDMA as a primary form of orthogonal multiple access (OMA) has been widely employed for the 4G network. In TDMA and OFDMA schemes, different users are assigned to be served in different orthogonal resource in time or frequency domain correspondingly. The spectral efficiency of these conventional orthogonal multiple access schemes is small since the limited bandwidth resource is not well-used in the case that a single user with poor channel gain occupies the whole bandwidth. On the other hand, CDMA scheme operates under the condition that its chip rate is much higher than its information data rate. Due to the stringent demand of handling ultra-high data rate in the 5G network, e.g. 10 Gbps peak data rate, expecting the chip rate to be fast enough and overtake the information data rate is unrealistic due to the limitation of hardware at present [3], [4].

As [4] - [7] mentioned, NOMA is an upcoming physical layer communication technique, has made a promising candidate in the field of the 5G wireless communication systems. By using non-orthogonal resource allocation, NOMA multiplexes multiple users into one subcarrier to allow the share of resource between users, which result in the sufficient use of the bandwidth resource and the improvement in spectral efficiency. NOMA enables multiple users to transmit information on the same frequency resource at the same time with different power levels, in other words, the BS can serve multiple users on the same frequency resource at the same time, which has a significant impact on latency reduction during transmission. Since NOMA tends to gather users with distinctive channel gains into the same subcarrier, and allocate the user with poor channel gain into high power level. As a result, the data rate of the weak users is boosted compared to conventional OMA. However, based on [6] - [9], because multiple users are multiplexed during transmission, the mutual interference is unavoidable. A proper interference management is expected. In NOMA scheme, the user with the better channel condition is responsible to minimise the interferences and noise in the system by decoding and employing SIC at the receiver, according to [12], [19], [22], [27] and [37]. By using power allocation scheme and user pairing selection scheme, NOMA provides a substantial improvement in spectral efficiency, latency, and user fairness.

In this project, we aim to design a computational efficient resource allocation scheme which maximizes the system spectral efficiency. In particular, the resource allocation design is formulated as a non-convex optimization problem which takes into account the user channel conditions, user data rate requirement, and the maximum transmit power constraint.

II. Literature Review

A. Comparison of NOMA and conventional OMA

OMA has been widely used in past few decades in existing mobile communication systems, e.g. 4G LTE, 3G, 2G, etc. In those conventional multiple access schemes, different users are allocated to orthogonal resources in either the time or the frequency domain in order to alleviate inter-user interference. However, it comes at the expense of low spectral efficiency based on [1], [4], [12], [13].

For example, as shown in Figure 1, in OFDMA schemes that commonly used in current 4G communication systems, a given wide frequency band is divided into multiple orthogonal subcarriers. Since OFDMA is trying to minimize inter-user interferences, which results in that system only allows each subcarrier to be allocated to at most one user. Whereas, NOMA is capable of assigning multiple users into one subcarrier to share the transmitted power on the same frequency resource or in the same time slot, refers to [20], [25], [28] and [35]- [39].

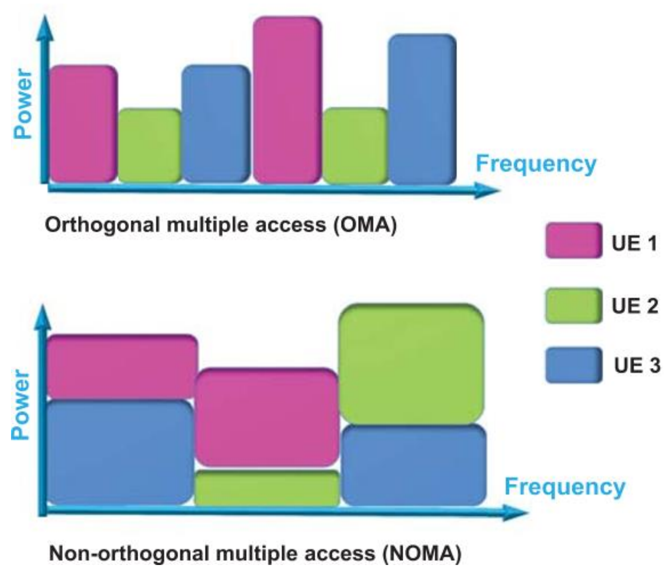

Figure 1 A comparison between NOMA and OMA in frequency domain.

Also, in most of the practical scenarios, conventional OMA allocates all the resources to the user with the best channel gain for maximizing the system data rate. However, such an allocation does not pay much attention to the weak users, conventional OMA tends to ignore the weak user at most of the time [4]. While, according to [4], [6], [7] and [9], NOMA is able to balance the resource allocation fairness between two paired users, which is beneficial to the users with a poor channel conditions in the system. It is obvious to be seen that a certain fairness between users is generated in NOMA scheme.

Due to the unfairness in resource allocation between users, as mentioned above, in conventional OMA, the user with the poor channel gain is required to wait for transmission while using time division. In contrast, since NOMA enables multiple users to share the resources on the same frequency domain, the base station can serve multiple users at the same time. As a result, the latency during transmitting data is significantly reduced, compared to OMA [1], [4].

Since two users are paired on each subcarrier, mutual interference is expected between them. In fact, the performance of NOMA is sensitive to the design of resource allocation for mitigating interference. Particularly, careful power control is needed at the transmitter side to harness the interference [4]. Besides, successive interference cancellation should be performed at the receiver of strong user. On the other hand, user pairing is also important for interference management, [6] - [9], [17]- [26].

Compared to conventional OMA scheme, NOMA has a better performance in the aspects of spectral efficiency, latency, and user fairness, which is promising solution for the fundamental issues in the 5G communication network requirements. However, due to the existed mutual interference between users in NOMA scheme, interferences are expected to be managed during transmission, stated in [4], [7], [17], [34], [35] and [41].

B. Motivation

Nowadays, heterogeneous and stringent requirements for the 5G of the wireless communication system are imposed to equip with the fast growth of mobile internet and rapid development of IoT. For example, it is expected there will be 50 billion wireless communication devices by 2020 due to the roll-out of IoT [10]. Based on the released data from Cisco VNI Mobile Data Traffic Forecast (2015-2020), as provided in Figure 2, the global mobile data is expected to increase 8-fold from 2015-2020 and the data traffic predicts to reach to 30.6 exabytes per month [11].

However, spectrum resource is limited in practical systems. Therefore, the requirements for the next-generation of the wireless communication system should be upgraded to be able to handle explosive data traffic, in other words, achieving high spectral efficiency with limited spectrum is necessary.

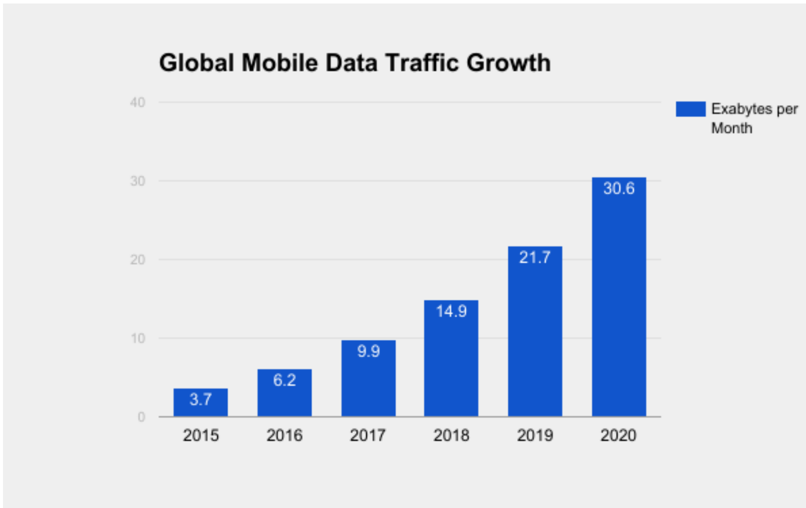

Figure 2. Global mobile data growth presented by histogram.

Due to the increasing demand of the Internet-of-Things (IoT) with various Quality-of-Service (QoS) requirements, the new multiple access technologies should be capable of supporting massive connectivity of users and/or devices, which demands low latency in transmission [1] - [3], [29]- [37]. According to [2], "Leading the world to 5G", conducted by Qualcomm Technologies Inc., in addition to the requirements as stated above, deep and universal coverage is also one of the needs in 5G networks, which means the new qualified multiple access technologies are encouraged to reach challenging locations. Therefore, guaranteeing user fairness is required in the 5G networks and the weak users in the system should be considered as important as other users, instead of ignoring them, according to [1]- [9], [15], [22], [23], [30], [31], [40] and [41].

As a result, NOMA has been considered as a promising candidate for the 5G mobile networks to fulfil these stringent requirements. In fact, various industrial companies, such as Huawei technologies and NTT DOCOMO, are pushing this technology into the standard of 5G. So, there is an emerging need in studying NOMA. Unfortunately, NOMA is yet to become a mature and qualified multiple access technology. There are various fundamental issues in practical implementation. For instance, one critical problem in NOMA scheme is that its system performance is sensitive to resource allocation [1], [4]. However, the efficient algorithm is still unknown at this point in the literature on studying NOMA, based on [7], [12], [14]- [19], [20], [32] and [36]- [39].

III. System Model

In this work, a downlink communication scenario with one Base Station and two users are considered. Without loss of generality, it is assumed that user *m* and user *n* are paired together for NOMA scheme as an illustration. In this work, there are two users on each subcarrier since the increasing number of users multiplexed on the same subcarrier cause the growth of hardware complexity and processing delay. Therefore, the case of two users per subcarrier is studied in the system model.

A. NOMA System Overview

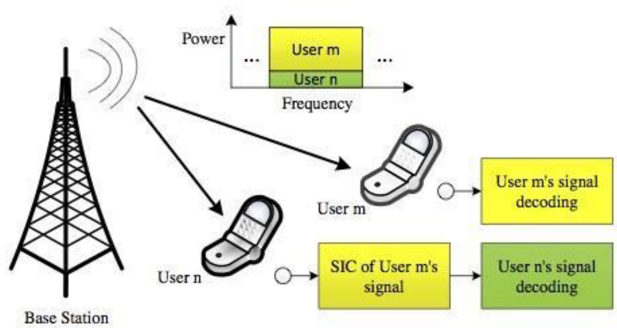

Figure 3. A system model of NOMA communication system.

Figure 3 shows that there are two users that multiplexed into one subcarrier. User *n* is closer to the BS compared to User *m*, which implies User *n* has a better channel condition comparing to User *m*. The Base Station optimizes the transmit power for each user on each subcarrier. In particular, instead of allocating all the power to one User, User *n* with stronger channel condition is allocated less transmitted power and more transmit power is allocated to User *m*. Compared to conventional OMA, User *m* is allocated with non-zero power which provides certain fairness in resource allocation.

Assigning User *n* with less power leads a small decrease in its capacity but a significantly good effect on User *m*'s. Therefore, user pairing and power allocation are able to strike a balance between the system performance and resource allocation fairness.

B. Interference Management

During transmission, there are some interference and noise existed in the system, such as co-channel interference (CCI) and white Gaussian noise, refers to [4], [7], [17], [34] and [35]. In this section, the impact of interference on the system performance and interference management in NOMA scheme are discussed by using mathematical equations.

The received signals at user m and user n on subcarrier i are given by

$$y_m^i = \sqrt{P_m^i \rho_m} h_m^i x_m^i + \sqrt{P_n^i \rho_m} h_m^i x_n^i + z_m^i, \text{ and}$$
$$y_n^i = \sqrt{P_n^i \rho_n} h_n^i x_n^i + \sqrt{P_m^i \rho_n} h_n^i x_m^i + z_n^i, \quad (1)$$

where x_m^i denotes the symbol transmitted from the BS to user m on subcarrier i; p_m^i denotes the transmitted power of the signal intended for user m on subcarrier i; h_m^i denotes the small-scale fading coefficient variable; ρ_m denotes the joint effect of path loss and shadowing between the BS and user m; z_m^i denotes the white Gaussian noise on subcarrier i at user m.

We assume $|h_m|^2 \geq |h_n|^2$, which indicates User *m* is further away from BS and has a poor channel condition compared to User *m*. The average of the message transmitted $\varepsilon\left\{\left|x_m^i\right|^2\right\} = 1$ without loss of generality, where $\varepsilon\{\ \}$ denotes the statistical expectation [7].

In NOMA scheme, only the strong user is able to decode and remove CCI from the weak user by employing SIC. For User *n*, as the strong user in the system model. At first, under a certain condition that is $log_2\left(1 + \frac{p_m^i \rho_n |h_n^i|^2}{z_n^i + p_n^i \rho_n |h_n^i|^2}\right) \geq log_2\left(1 + \frac{p_m^i \rho_m |h_m^i|^2}{z_m^i + p_n^i \rho_m |h_m^i|^2}\right)$, x_m is decoded, which result in User *n*'s achievable rate at this stage is $log_2(1 + \frac{p_n^i \rho_m |h_m^i|^2}{z_m^i + p_m^i \rho_m |h_m^i|^2})$ and the value of SINR is $\frac{p_n^i \rho_m |h_m^i|^2}{z_m^i + p_m^i \rho_m |h_m^i|^2}$. Next, the x_m is obtained from the received signal y_n^i by performing a subtraction, $y_n^i - \sqrt{P_m^i \rho_n} h_n^i x_m^i = \sqrt{P_n^i \rho_n} h_n^i x_n^i + z_n^i$, so that the interference caused by User *m* is removed. Then, SIC is performed at the receiver end. The achievable rate after employing SIC is $log_2(1 + \frac{p_n^i \rho_n |h_n^i|^2}{z_n^i})$ and SINR at this stage is $\frac{p_n^i \rho_n |h_n^i|^2}{z_n^i}$. It is obvious that SINR is reduced after applying SIC. In NOMA, User m, as a weak user, also has an achievable rate given by

$log_2(1 + \frac{p_m^i \rho_m |h_m^i|^2}{z_m^i + p_n^i \rho_m |h_m^i|^2})$, which suggests both users in the system can get a certain amount of data rate. Whereas, in conventional OMA, due to the orthogonal subcarrier allocation, it may not be possible to gain a certain amount of data rate for the weak user.

IV. Problem Formulation

In this section, the instantaneous weighted throughput is first defined to be the adopted performance measure for the NOMA system. Subsequently, the power and subcarrier allocation design problem is formulated as an optimization problem.

A. The instantaneous weighted throughput

According to [7], [12] and [16]- [28], the key concept in NOMA scheme is that system assigns different level of power recourse to the multiplexed users with various channel condition so that the system performance can be maximized. Since multiple users are multiplexed into one subcarrier, mutual interference is unavoidably introduced into the system and should be removed by employing SIC. In particular, for a given subcarrier *i*, user *n* is defined as the user with strong channel gain in the two user-paired system, which means only user *n* is capable of decoding and applying SIC to eliminate CCI. The other user *m* is treated as the weak user that multiplexed with user *n* on the same subcarrier *i*. Therefore, the instantaneous weighted throughput on subcarrier *i* is given by

$$U_{m,n}^{i}\left(p_{m}^{i}, p_{n}^{i}, s_{m,n}^{i}\right) = s_{m,n}^{i}\left[\omega_{m} log_{2}\left(1 + \frac{p_{m}^{i}\rho_{m}\left|h_{m}^{i}\right|^{2}}{z_{m}^{i} + p_{n}^{i}\rho_{m}\left|h_{m}^{i}\right|^{2}}\right) + \omega_{n} log_{2}(1 + \frac{p_{n}^{i}\rho_{n}\left|h_{n}^{i}\right|^{2}}{z_{n}^{i}})\right] \tag{2}$$

where ω_m is a positive constant with the range of $0 \leq \omega_m \leq 1$, it denotes the priority of user *m* in resource allocation. The subcarrier allocation indicator is a binary variable which is given by

$$s_{m,n}^{i} = \begin{cases} 1, & if\ user\ m\ and\ user\ n\ are\ multiplexed\ on\ subcarrier\ i\ with\ H_{m}^{i} \leq H_{n}^{i} \\ 0, & otherwise \end{cases} \tag{3}$$

where $H_{m}^{i} = \frac{\rho_{m}\left|h_{m}^{i}\right|^{2}}{z_{m}^{i}}$, and $H_{m}^{i} \leq H_{n}^{i}$ is defined.

B. Optimization Problem Formulation

In this project, our design aims to maximize the weighted throughput in the system via designing the jointly optimal power and subcarrier allocation policy. The policy design can be formulated as the following optimization problem:

$$\underset{\boldsymbol{p},\boldsymbol{s}}{maximize} \sum_{i=1}^{N_F} \sum_{m=1}^{K} \sum_{n=1}^{K} U_{m,n}^{i}\left(p_{m}^{i}, p_{n}^{i}, s_{m,n}^{i}\right),$$

$$s.t. \quad C1: \sum_{i=1}^{N_F} \sum_{m=1}^{K} \sum_{n=1}^{K} s_{m,n}^{i}\left(p_{m}^{i} + p_{n}^{i}\right) \leq P_{max},$$

$C2: s^i_{m,n} \in \{0,1\}, \ \forall\, i, m, n,$

$C3: \sum_{m=1}^{K} \sum_{n=1}^{K} s^i_{m,n} \ \leq \ 1, \ \forall i,$

$C4: p^i_m \ \geq 0, \ \forall i, m.$ (4)

C1 is the power constraint for base station where P_{max} is the maximum transmit power allowance. C2 is the constraint for the binary optimization variables. C2 and C3 are imposed to guarantee that each subcarrier is allocated at most 2 users. C4 is the non-negative transmit power constraint.

In fact, the problem is a non-convex optimization problem. In other words, there is no well-known systematic and efficient approaches for solving these problems.

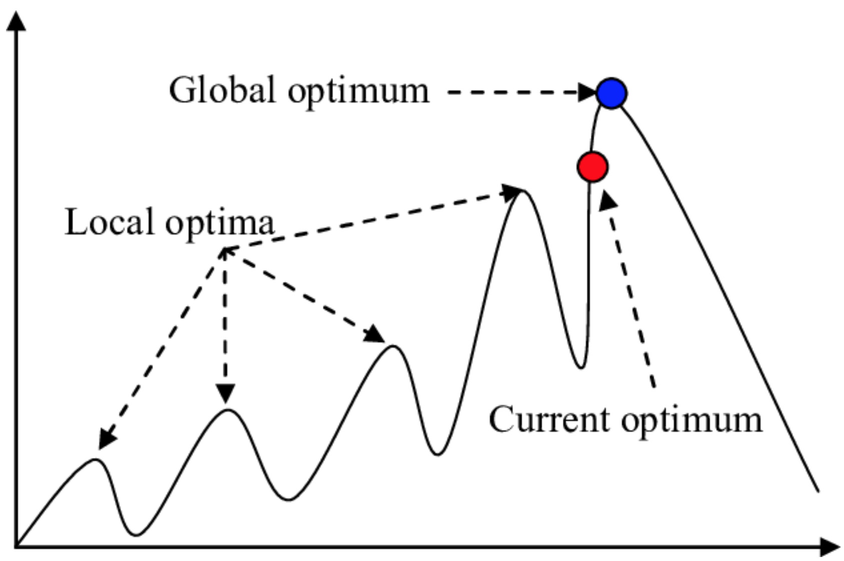

Figure 4 A illustration of non-convex optimization.

As shown in Figure 4, to spot a global optimum, all local optima should also be obtained for comparison as well. In two-dimensional space, there are multiple local optima points. All the points are expected to be found out in order to achieve to the globally optimal solution. More importantly, in high dimension, the number of points that needs to be searched are usually growing exponentially with the numbers of optimization variables. Consequently, finding the globally optimum solution is computationally intensive and may be infeasible for devices with limited computational capability. A suboptimal design, which can strike a balance between computational complexity and performance for NOMA systems is proposed and introduced in the section of detailed design.

V. Detailed Design

It needs to be mentioned that the proposed algorithm is not the optimal design for solving the non-convex optimization problem as mentioned in the section of problem formulation. Since the formulated problem is a high-dimensional optimization problem, which means the number of possible solutions grow exponentially with respect to the numbers of optimization variabless. It is impossible to obtain the best solution without doing exhaustive research. Thus, the proposed algorithm is defined as a suboptimal solution for solving this optimization problem.

A. User Pairing Algorithm

The conventional user selection algorithm, namely channel gain-based selection scheme, tends to focus on pairing two users only according to their distinctive user channel gain and underestimate the importance of considering user data rate requirements in NOMA system. Thereby, to optimize the user pairing selection, the proposed user pairing scheme, namely user data rate requirement-based selection scheme, takes into account both user channel conditions and user data rate requirements.

For user pairing solution, the designed work basically revolves around finding a suboptimal solution by balancing between user's channel condition and user data rate requirement. One of the possible solution of user pairing that mentioned at the primary stage is to put two factor, which are user channel condition and user data rate requirement, into one metric through multiplication of them. In that way, both user channel gain and user data requirement weigh equally in the system. Whereas, it is likely to exist such situation that two users from a paired group do not have distinctive channel condition, since the strong user and weak user in NOMA system are not distinguished by user channel gain, but by the multiplication of channel gain and data rate requirement, instead. Therefore, this solution is abandoned and excluded in the proposed algorithm.

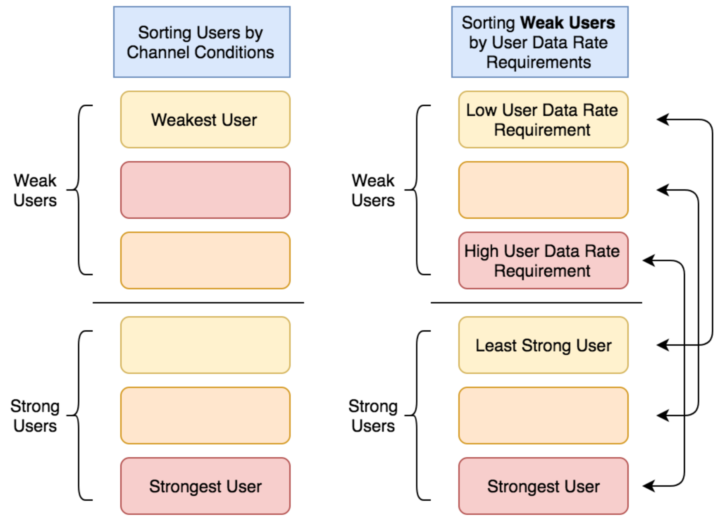

Figure 5 The proposed user pairing algorithm.

The proposed algorithm is illustrated by Figure 5. First, by sorting all users based on their channel gains, which the user with the strongest user channel gain is ranked first, the proposed scheme classifies the first half of users that placed in the front into strong users group in the system and the rest users are treated as weak users. Only weak users are allowed to be paired up with strong users, which ensures that two users in every two-user paired group have distinctive channel gains and thereby enhance the performance gain achieved by NOMA compared to OMA. Second, since all strong users and weak users are being distinguished, the proposed algorithm considers weak users' data rate requirements by sorting weak users again but based on their data rate requirements. The reason that strong users' data rate requirements are being neglected is the limitation of improvements on their achievable data rate due to their better channel conditions that in contrast to weak users. Then, the proposed user pairing scheme favorites the weak user with the highest user data rate requirement and pair it up with the strongest user in the system. The weak user that has a low user data rate requirement is treated as the weak user with the least priority in the system, and therefore being selected to group with the least strong user.

This algorithm clearly shows its rule regarding user pairing selection, which is defined that the user with a more stringent requirement for its data rate has the higher priority in user selection scheme.

B. Power Allocation Algorithm

One of the conventional suboptimal power allocation solutions is equal power allocation. Specifically, the transit power of the base station is equally distributed to each subcarrier, which can be easily implemented in practice but lack of effectiveness. The designed power allocation solution is proposed to maximize the system performance to certain extent. The main direction of solving the power allocation problem in the designed work is convex optimization approach, refers to [7], [12], [16], [17] and [32]. The structure of the optimization problem is exploited and thereby a locally optimal solution is expected to be found out via computational efficient algorithms.

The proposed power allocation algorithm has two convex optimization approaches, which targets on optimizing both the allocated power to each paired user in each subcarrier and the transmit power that distributed to each subcarrier.

1. Optimization Problem for Power Allocation Per Subcarrier

The convex optimization approach regarding power allocation to each paired user in each subcarrier is given by

$$\underset{\boldsymbol{p_m^i}, p_n^i}{maximize} \; R = \omega_m log_2\left(1 + \frac{H_m^i p_m^i}{1 + p_n^i H_m^i}\right) + \omega_n log_2(1 + H_n^i p_n^i),$$

$$s.t. \quad C1: p_m^i + p_n^i \leq p_{max}^i,$$

$$C2: p_m^i \geq 0, \; p_n^i \geq 0. \tag{5}$$

The objective function that applied in the convex optimization problem (5) is the weighted throughput on subcarrier i. The constraint function $C1$ implies the sum of power that distributed to each paired user in each subcarrier at most equals to the power that assigned to this subcarrier. In order to maximize the objective function, in general, all the power that assigned to the subcarrier should be used up by the two paired-up users, which indicates the sum of power that allocated to two users in the subcarrier equals to the maximum power that distributed into this subcarrier by the proposed algorithm. The constraint function $C2$ represents the non-negative nature of powers for selected users.

2. Solution for Optimizing Power Allocation Per Subcarrier

In subcarrier i, p_n^i denotes the power that assigned to the strong user. For fixed p_n^i, the rising of achievable data rates in the overall subcarrier *i* is associated with the increasing of the power that assigned to the weak user, which is p_m^i. Then, the relevant equation, $p_m^i = p_{max}^i - p_n^i$, should be established so that the achievable rate of the weak user, $R(p_m^i)$, can be maximised. Thus, the achievable rate of the weak user is given by

$$R = \omega_m log_2\left(1 + \frac{H_m^i(p_{max}^i - p_n^i)}{1 + p_n^i H_m^i}\right) + \omega_n log_2\left(1 + H_n^i p_n^i\right)$$

$$= \omega_m log_2\left(1 + H_m^i\, p_{max}^i\right) - \omega_m log_2\left(1 + p_n^i H_m^i\right) + \omega_n log_2\left(1 + H_n^i p_n^i\right) \tag{6}$$

Then, to find extreme point, the integral of $R(p_m^i)$ with respect to p_m^i is shown as following,

$$\frac{dR(p_m^i)}{dp_m^i} = -\frac{\omega_m H_m^i}{\left(1 + p_n^i H_m^i\right)\ln 2} + \frac{\omega_n H_n^i}{\left(1 + p_n^i H_n^i\right)\ln 2}$$

$$= \frac{(\omega_n H_n^i - \omega_m H_m^i) - (\omega_m - \omega_n) H_m^i H_n^i\, p_n^i}{\left(1 + p_n^i H_m^i\right)\left(1 + p_n^i H_n^i\right)\ln 2} \tag{7}$$

NOMA scheme tends to gives weak user high user priority in power allocation in each subcarrier, which implies $\omega_m \geq \omega_n$, should be fulfilled. Additionally, the non-negative power constraint should be satisfied as well. As a result, the zero point of $\frac{dR(p_m^i)}{dp_m^i}$ is given by

$$p_m^i = \frac{(\omega_n H_n^i - \omega_m H_m^i)}{(\omega_m - \omega_n) H_m^i H_n^i} \tag{8}$$

Therefore, the maximum value of R is achieved under the conditions that $p_m^i = \frac{(\omega_n H_n^i - \omega_m H_m^i)}{(\omega_m - \omega_n) H_m^i H_n^i}$ and $p_m^i = p_{max}^i - p_n^i$.

3. Optimization Problem for Power Allocation to Each Subcarrier

The convex optimization approach regarding the transmitted power allocation to each subcarrier is given by

$$\underset{\boldsymbol{p_{max}^i}}{maximize} \sum_{i=1}^{N_i}\left[\omega_m log_2\left(1 + \frac{H_m^i p_m^i}{1 + p_n^i H_m^i}\right) + \omega_n log_2(1 + H_n^i p_n^i)\right],$$

$$s.t. \quad C1:\ \sum_{i=1}^{N_i} p_{max}^i \leq P_{max}. \tag{9}$$

The primal constraint function $C1$ is subjected to ensure all the powers that distributed to each subcarrier do not exceed the maximum transmit power in the system. To optimize the use of power resource, all the maximum transmit power should be distributed into subcarriers. Also, N_i denotes the overall number of subcarriers in the system.

4. Solution for Optimizing Power Allocation to Each Subcarrier

As stated above, for maximum weighted throughput on subcarrier i, $p_m^i = \frac{(\omega_n H_n^i - \omega_m H_m^i)}{(\omega_m - \omega_n) H_m^i H_n^i}$ and $p_m^i = p_{max}^i - p_n^i$ are derived equations that requires to be satisfied. Hence, the objective function can be simplified into $\sum_{i=1}^{N_F} \omega_m log_2 \left(1 + \frac{H_m^i (p_{max}^i - p_n^i)}{1 + p_n^i H_m^i}\right)$, seeing that $\omega_n log_2 (1 + H_n^i p_n^i)$ is treated as a constant for solving this optimization problem.

Considering the simplified primal function shown above and its constraint, the Lagrange equation for maximization is given by

$$L = -\sum_{i=1}^{N_F} \omega_m log_2 \left(1 + \frac{H_m^i (p_{max}^i - p_n^i)}{1 + p_n^i H_m^i}\right) + \lambda(\sum_{i=1}^{N_F} p_m^i - p_{\max}^i) \tag{10}$$

Thus, the Lagrange dual function is given by

$$\underset{\lambda \geq 0}{maximize} \; \underset{p_{max}^i}{inf} \; L = -\sum_{i=1}^{N_F} \omega_m log_2 \left(1 + \frac{H_m^i (p_{max}^i - p_n^i)}{1 + p_n^i H_m^i}\right) + \lambda(\sum_{i=1}^{N_F} p_m^i - p_{\max}^i) \tag{11}$$

According to KKT condition, the extreme point is taken by

$$\frac{dL}{dp_{max}^i} = -\frac{H_m^i}{\left(1 + p_n^i H_m^i + H_m^i (p_{max}^i - p_n^i)\right) \ln 2} + \lambda = 0 \tag{12}$$

By solving equation (12), the values of λ and p_{max}^i are given by

$$\lambda = \frac{H_m^i}{\left(1 + p_n^i H_m^i + H_m^i (p_{max}^i - p_n^i)\right) \ln 2} \tag{13}$$

$$p_{max}^i = \left[\frac{1}{\lambda \ln 2} - \frac{1 + p_n^i H_m^i}{H_m^i}\right]^+ \tag{14}$$

the optimized solution for power allocation to all the subcarrier can be found when $\lambda = \frac{H_m^i}{\left(1+ p_n^i H_m^i + H_m^i (p_{max}^i - p_n^i)\right) \ln 2}$ and $p_{max}^i = \left[\frac{1}{\lambda \ln 2} - \frac{1+ p_n^i H_m^i}{H_m^i}\right]^+$.

However, due to computational complexity of finding the optimal points, all optimization problems are solved by employing CVX modeling system via Matlab.

VI. Simulation Approach

All simulations are implemented via Matlab.

A. Simulation Design

The system model that used for simulation is a downlink communication scenario with two users per subcarrier and single antenna, that is NOMA-OFDM. The number of downlink users is set to be 6 for analysis on average system throughput and weak user's achievable data rate. In all the simulations, the number of subcarriers in the system model is fixed to 64. Due to the limited time for simulations, the implementation loops have been downsized. The numbers of path loss realization and channel realization are assigned to be 100 and 1 respectively. The data that obtained under this circumstance may have a small impact on the accuracy of the results but is enough to present various algorithms' trends in their system performances. In order to get more accurate data for analyzing multiuser diversity, the number of path loss realization is changed to 1,000. The algorithms that described as following are simulated user pairing models for analysis.

1. Proposed Algorithm

The explicit explanation of the proposed algorithm is stated in Detailed Design. Concisely, the proposed algorithm mainly optimizes user pairing scheme in NOMA. Accordingly, its compared algorithms are the algorithms that have various user selection scheme but use the same power allocation solution.

2. Compared Algorithms

All compared algorithms perform user pairing based on only the channel gains of users. The selection algorithms, except random user pairing algorithm, ensure that two users in every two-user paired group have distinctive channel gains, which maximize the performance gain achieved by NOMA in contrast to OMA. The compared algorithms that employed in simulations are described and shown below in this section.

Random pairing algorithm is the user pairing scheme that pair two users randomly and without considering both users' channel conditions and users' data rate requirements. This method of user selection has the least complexity to be performed in NOMA system. However, it also the most ineffective algorithm in user pairing since the condition that two users in every two-user paired group have distinctive channel gains cannot be guaranteed. In addition, there is a possibility that not all the users are being selected and paired up by applying random pairing algorithm, which implies lack of user fairness.

Conventional user pairing algorithm only devotes its effort to the strongest and weakest users for user pairing in NOMA system, which highlights the lack of user fairness that existed in this user selection scheme. On the other hand, two users with the most distinctive channel conditions share the power resource allocated inside a subcarrier, which is expected to have the best outcome on the achieved performance gain, compared to other compared algorithms.

The low-complexity channel gain-based user pairing algorithm that illustrated in Figure 6. were established at primary work stage as a proposed user selection scheme.

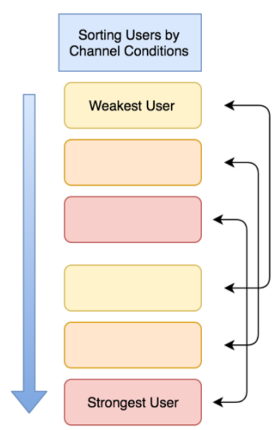

Figure 6 The low-complexity user pairing algorithm.

This user pairing algorithm ensures every two paired users in the system has certain different channel gains. However, the difference between two paired users channel condition is not being maximized, which is not efficient for user pairing. Also, this method of user pairing guarantees every user in the system is selected into at least one subcarrier so that user fairness is able to be strengthened.

B. Simulation Results

The performances on the average system throughput and weak user's achievable data rate have been analyzed and the results are shown below. Additionally, the multiuser diversity of the proposed algorithm has been examined as well.

1. Average System Throughput

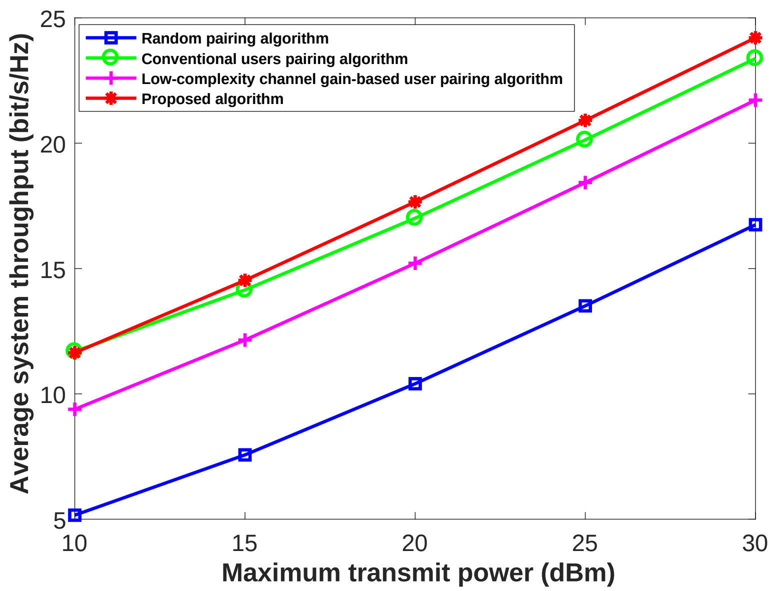

Figure 7 Average system throughput VS Maximum transmit power.

It is clearly illustrated by Figure 7. that the proposed algorithm has the best system performance on weighted system throughput, compared to other simulated algorithms. The proposed algorithm has more efficient performance on average system throughput while increasing the amount of maximum transmit power.

As expected, random pairing algorithm has the worst outcome regarding average system throughput due to it ineffectiveness on user selection. The low-complexity channel gain-based user pairing algorithm ensures every user inside system is selected and allocated into each subcarrier, which comes at the expense of low weighted system throughput in contrast to the conventional user pairing algorithm that lack of caring user fairness. The conventional user selection scheme that sacrificing user fairness for improvement on the weighted throughput on each subcarrier, as predicted, has a great result on average system throughput, especially when the maximum transmit power is less than 12 dBm. However, it tends to lose its leading position with the increment of the maximum transmit power that used in the system. While the amount of maximum transmit power that put into the system keeps increasing, the superiority of applying the proposed algorithm for enhancing average system throughput is more obvious. In other words, the gap of the system throughput performances between the proposed algorithm and the conventional one is enlarged while scaling the transmit power. That is because the proposed algorithm has higher flexibilities for utilizing the degree of freedom among all other compared user pairing schemes.

2. Weak User Achievable Data Rate

Seeing that the proposed algorithm performance on the average system throughput is extremely closed to the conventional algorithm system performance and the weak user have a high priority for power allocation in each subcarrier in NOMA, those two user pairing schemes are selected for comparison of weak user's achievable data rate.

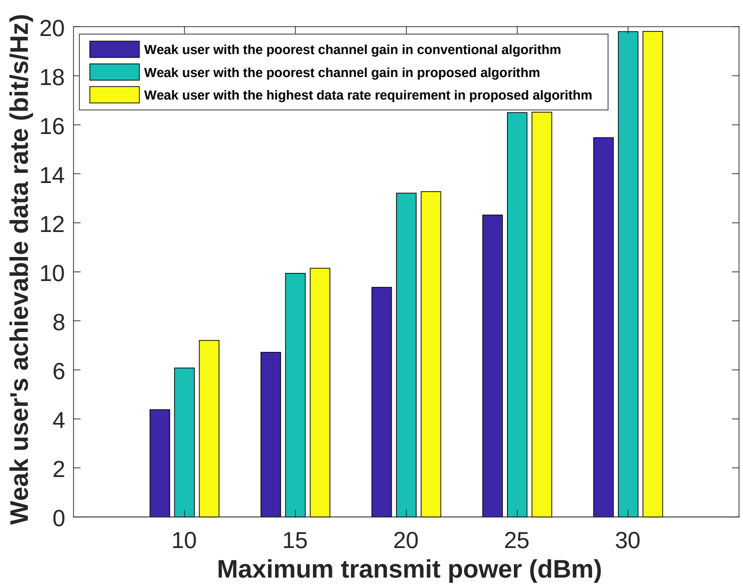

Figure 8 Weak User's Achievable Data Rates VS Maximum transmit power.

Shown by Figure 8, the weak user's achievable data rate in the simulated system based on the proposed algorithm is improved remarkably. The reason that the proposed scheme has a better outcome on improving the weakest user's achievable data rate is that it has a high level of flexibilities for exploiting the use of the degree of freedom, compared to the conventional user selection scheme.

Since the proposed algorithm devotes its effort to improve the achievable data rate of the weak user with a more stringent requirement for its data rate, its system performance on achievable data rate is inspected as well. The results are showing that the proposed algorithm favorites the weak user with the highest data rate requirement rather than the weak user with the poorest channel gain when the maximum transmit power is limited. However, when system has sufficient transmit power, all weak users' achievable data rates are significantly increased in spite of data rate requirements and channel gains. In other words, the proposed algorithm has a substantial achievement on user fairness.

3. Multiuser Diversity

Due to time limitation, only the proposed user selection scheme has been tested in the aspect of multiuser diversity. The number of path loss realization is changed from 10 to 1,000 for accuracy. The test result is illustrated in Figure 9.

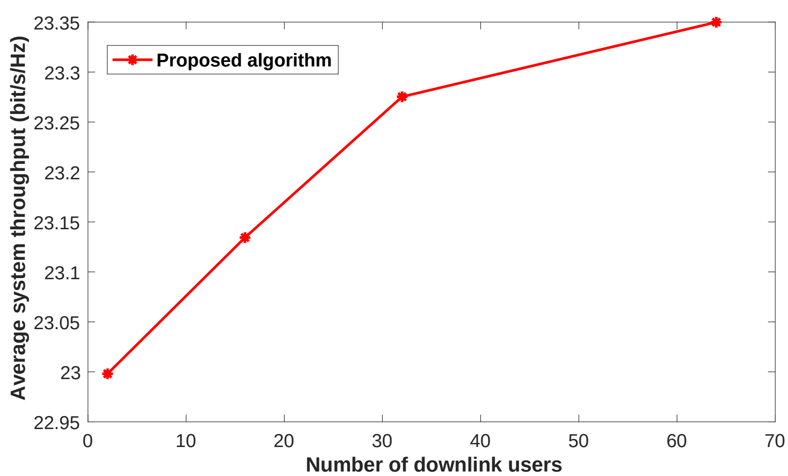

Figure 9 Weak User's Achievable Data Rates VS Number of Downlink Users.

It is evident that the slop of increment is being decreased and as a result, the average system throughput by employing the proposed algorithm will reach to its saturation state, which is around 23.35 bit/s/Hz, while increasing the number of downlink users. However, the saturated value of system performance on average throughput by applying the conventional algorithm is being estimated as around 25.60 bit/s/Hz, which is much more impressive in contrast to the proposed algorithm. Seeing that it is doubtless that the weighed system throughput is heightened with the increasing of downlink user, a noticeable decline in its rate of increments also appears while the number of users that involved is boosted. Since it is challenging to create user fairness among a large number of downlink users, it is an acceptable outcome that the saturated value on average system throughput by using the proposed algorithm is much small than using the conventional algorithm, which trends to neglect the user fairness in exchange of elevating system throughput.

To summaries, the proposed user pairing algorithm provides superior improvements in aspect of the weighted system throughput and user fairness, compared to other simulated user pairing algorithms, which meets the objectives. Whereas, not as expected, the proposed scheme's system performance on multiuser diversity is not impressive in contrast to the conventional algorithm, due to its intention of ensuring user fairness in the system.

VII. Future Work

The system model that employed and analyzed is a downlink communication system with single antenna. The development plan on the proposed design is to apply MIMO (multiple-input multiple-output) technique into NOMA system, which indicates that the system model will be modified into a wireless communication scenario with multi antenna. In addition, another future direction is to design a computational resource allocation algorithm including beamforming design, user scheduling design and successive interference cancellation order design.

VIII. Conclusion

To date, the literature review on the NOMA related works for 5G communication networks has been presented in this report. A systematic approach to analyze the differences between NOMA and OMA has been provided. Specifically, the benefits in applying NOMA over OMA are revealed. Besides, the design has been formulated by using optimization framework. The proposed algorithm with low computational complexity, namely data rate requirement-based scheme, has considered user channel condition, user data rate requirement and the maximum transmit power constraints, which conventional algorithms fails to do. By simulation of various user pairing algorithm via Matlab, the proposed user selection scheme has shown its superior performance on the average system throughput and user fairness in contrast of other conventional algorithms. Whereas, its intention of ensuring user fairness comes at the expense of unimpressive outcome on its multiuser diversity. In addition, the future directions for extending my current works has been outlined as well.

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