Proportional Fairness-Based User Pairing and Power Allocation for Non-Orthogonal Multiple Access

Fei Liu, Petri Mähönen, Marina Petrova
Institute for Networked Systems, RWTH Aachen University
Kackertstrasse 9, D-52072 Aachen, Germany
Email: {fei}@inets.rwth-aachen.de

***Abstract*—The non-orthogonal multiple access (NOMA) has been investigated recently as a candidate radio access technology in future mobile networks. It is able to implement power-domain user multiplexing based on successive interference cancellation (SIC). This paper focuses on the user pairing and power allocation problem in the 2-user NOMA system. The optimal solution in closed-form is derived with the proportional fairness objective and is used for the design of the user pair power allocation scheme. The prerequisites for user pairing are also formulated in order to avoid unnecessary comparison of candidate user pairs. The performance of the proposed scheme is evaluated by system-level simulations and results in higher gains than the search-based transmission power allocation. On the other hand, the computational complexity is reduced by the proposed scheme effectively.**

***Index Terms*—Non-orthogonal multiple access, user pairing, power allocation, proportional fairness.**

I. Introduction

The continuous growth of mobile data services has triggered the investigation of 5th generation mobile networks (5G) for the future development of wireless communications [1]. In the last generations of mobile networks, multiple access technologies, such as frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and orthogonal frequency division multiple access (OFDMA), were utilized as key technologies. In order to respond to the challenge of providing significantly higher system capacity in the upcoming decade, new radio access technologies (RATs) are desired. Non-orthogonal multiple access (NOMA) has been proposed and investigated as one of the candidate technologies for multi-user access [2]–[9]. Different from previous RATs, users can be multiplexed in the power domain by using the successive interference cancellation (SIC) technique in NOMA [2], [3]. The NOMA system can control the user multiplexing and transmission throughput by allocating different power levels to user radio links. Therefore, the user power allocation (PA) becomes a significant issue in additional to the resource scheduling problem in previous systems [4]–[6].

Several power allocation schemes for NOMA systems have been proposed in recent research literature and they can be broadly classified into two groups: fixed PA and dynamic PA. In the fixed PA scheme, the average channel quality of each user is considered for SIC order, and the power ratios between users are fixed [6], [8]. In contrast, the dynamic PA assigns transmit power based on the instantaneous user channel status. Fractional transmit PA (FTPA) is one simple and well investigated dynamic PA method, where the power ratio of each user is determined by their channel qualities [2]–[7]. The fairness in NOMA is considered as the optimization target in [9] to maximize the minimum data rate. In order to improve the performance of proportional fairness (PF) of user throughput, a PA algorithm is designed based on the iterative water-filling (IWF) method [6]. Recently, a tree-search based transmission PA (TTPA) method has been proposed with lower complexity than full search PA (FSPA) [4]. However, both IWF and TTPA suffer from the disadvantage of the searching or iteration operation for PA, which severely limits their practicability in real NOMA systems.

In this paper, we focus on the user pairing (UP) and power allocation problems in the 2-user NOMA system, where the requirement for the SIC receiver is minimum. We also adopt PF as the metric of UP and PA to guarantee the balance between transmission efficiency and user fairness. In order to reduce computational complexity of user scheduling, the prerequisites for user pairing are derived and utilized to avoid unnecessary comparison of candidate user pairs. Then, the closed-form optimal solution is derived with the PF objective and it is used for the design of the user pair power allocation (UPPA) scheme. We evaluate the performance of the proposed UPPA scheme in the NOMA system with system-level simulations and compare it with the TTPA-based NOMA as well as the conventional OFDMA system.

The rest of this paper is organized as follows. Section II describes the general SIC-based NOMA system model. In section III, we formulate the user pairing and power allocation problem and propose our UPPA scheme based on the derivation of the closed-form optimal solution. The simulation results of the proposed scheme are presented and analyzed in section IV. Finally, conclusions are drawn in section V.

II. System Model

We consider a downlink cellular network serving M users in each cell. The user index set is denoted as $\mathbf{U}_M = \{1, 2, ..., M\}$. The frequency bandwidth is divided into K resource blocks (RBs) with indices $k \in [1, K]$ as in OFDMA systems [10]. Successive interference cancellation is applied in the NOMA system to allow superposition of signals with different transmit power levels for different users [2]. We

978-1-4673-6782-0/15/$31.00 ©2015 IEEE

denote the set of users served simultaneously in a RB as $\mathbf{U}_k = \{l_k(1), ..., l_k(n), ..., l_k(N_k)\}$, where $l_k(n)$ is the user index of the n-th scheduled user in RB k. The size of $\mathbf{U}_k$, i.e., $N_k = |\mathbf{U}_k|$, is assumed to be smaller than a limitation N_{max} due to the processing complexity in the SIC receiver. So the scheduled users per RB is no more than N_{max} at the same time. Single antenna is used for both transmission and reception. Thus the received signal in RB k at its n-th served user is given as

$$y_{l_k(n)} = h_{l_k(n)} \sum_{i=1}^{N_k} s_{l_k(i)} \sqrt{P_{l_k(i)}} + I_{l_k(n)} + \sigma_{l_k(n)}, \quad (1)$$

where $h_{l_k(n)}$ is the comprehensive channel gain of path loss, shadow fading, and fast fading in amplitude. $s_{l_k(i)}$ denotes the data symbol and is assumed with a unit mean power value, i.e., $\mathbb{E}\left[s_{l_k(i)}\right] = 1$. $P_{l_k(i)}$ is the transmit power allocated to user $l_k(i)$. $I_{l_k(n)}$ represents the inter-cell interference signals, and $\sigma_{l_k(n)}$ denotes the additive white Gaussian noise.

In NOMA the BS controls the transmit power ratios assigned to its users. We assume that the BS allocates the power to all RBs equally. Thus $P_{l_k(n)}$ is expressed as

$$P_{l_k(n)} = \lambda_{l_k(n)} P_t / K, \quad n = 1, ..., N_k, \quad (2)$$

where P_t is the total transmit power of a BS, and $\lambda_{l_k(n)}$ is the power assignment ratio of user $l_k(n)$, which should satisfy the following conditions,

$$\sum_{n=1}^{N_k} \lambda_{l_k(n)} = 1, \quad \lambda_{l_k(n)} \in (0, 1).$$

We denote the channel quality indicator (CQI) of user $l_k(n)$ as $\phi_{l_k(n)}$. It is the reachable signal-to-interference-plus-noise ratio (SINR) with the full transmit power of the BS. Hence, $\phi_{l_k(n)}$ is calculated as

$$\phi_{l_k(n)} = \frac{P_t \left|h_{l_k(n)}\right|^2}{K P_{IN, l_k(n)}}, \quad (3)$$

where $P_{IN,l_k(n)}$ denotes the sum power of inter-cell interference and noise received by user $l_k(n)$.

In downlink NOMA systems, SIC is carried out in user receivers. We assume that the scheduled users in a RB are sorted in the descending order in terms of their CQIs, and the SIC receiver of user $l_k(n)$ can decode and cancel successively the interference from the user $l_k(n+1) \sim l_k(N_k)$ [5]. The post-processing SINR (PSINR) of user $l_k(n)$ after SIC is

$$\Phi_{l_k(n)} = \frac{\phi_{l_k(n)} \lambda_{l_k(n)}}{\phi_{l_k(n)} \sum\limits_{i=1}^{n-1} \lambda_{l_k(i)} + 1}. \quad (4)$$

For implementation of SIC, a user with better channel quality, namely, higher $\phi_{l_k(n)}$, has to be informed the modulation and coding schemes (MCSs) and power ratios of the users with lower CQIs. Then, user $l_k(n)$ needs to decode the signals and cancel the interference of user $l_k(n+1) \sim l_k(N_k)$ in the reverse order [5]. If N_k is large, the signaling cost and the processing complexity at user equipment are very high. Therefore, in this paper, we focus on the 2-user NOMA case, where $N_{max} = 2$. Thus, only one user with higher $\phi_{l_k(1)}$ may need to carry out SIC based on the MSC and power allocation information.

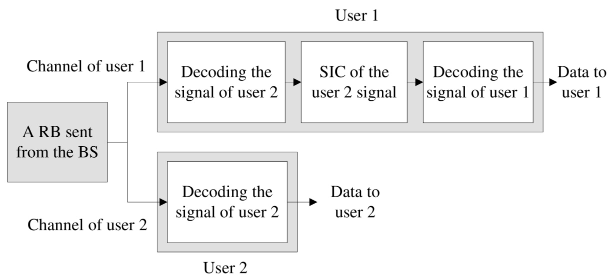

Fig. 1. Illustration of the 2-user NOMA transmission.

The reception and decoding procedure in a 2-user NOMA system is illustrated in Fig. 1. We assume that user 1 has better channel quality than user 2. Thus, user 1 firstly decodes and cancels the interference signal of user 2. Then, it decodes the desired signal of its own. No SIC is necessary at user 2. The interference signal of user 1 is regarded as noise during user 2 decoding.

III. User Pairing and Power Allocation

In order to improve the performance of NOMA systems, the users should be scheduled and allocated power according to the desired objective. With $N_{max} = 2$, there can be one or two users scheduled in each RB. So the number of candidate user sets for scheduling is $C_M^1 + C_M^2 = C_{M+1}^2$. If one user is scheduled, the full power of the RB will be allocated to it. If two users are scheduled with NOMA, the power ratios are necessary to be controlled delicately to enhance the desired performance. In this paper, we use a 2-step strategy, where the power allocation for each candidate scheduled user set is firstly optimized to achieve highest scheduling metric, and then the optimal user pair or single user with the maximum metric will be scheduled. In the following, we will first introduce the proportional fairness policy for user scheduling and then propose our user pair power allocation (UPPA) scheme.

A. Proportional Fairness Policy

PF has been proved to maximize the logarithmic sum of user throughput, so both efficiency and user fairness can be guaranteed [11]. It has been adopted as the objective of user scheduling and power allocation for NOMA systems in lots of works [3]–[7]. PF considers the instantaneous user data rate as well as the long term averaged rate, which is defined as

$$R_m(t+1) = \left(1 - \frac{1}{t_c}\right) R_m(t) + \frac{1}{t_c} \sum_{k=1}^{K} x_{m,k}(t)\, r_{m,k}(t),$$
$$k = 1, ..., K, \quad m = 1, ..., M, \quad (5)$$

where t_c is the averaging window size, $r_{m,k}(t)$ is the obtainable data rate of user m in RB k at t-th frame, and $x_{m,k}(t)$

is the scheduling 0-1 index. If user m in RB k at t-th frame is scheduled, it is 1, otherwise, 0. $r_{m,k}(t)$ is calculated by

$$r_{m,k}(t) = N_{sc} S_e \eta_{m,k}(t) / T_s = r_0 \eta_{m,k}(t), \tag{6}$$

where N_{sc} is the number of subcarriers in each RB, S_e is the number of effective symbols of one frame in the time domain, and T_s is the frame time duration [10]. The achievable spectrum efficiency, $\eta_{m,k}$, is calculated according to the selected MCS and the expected block error rate (BLER).

The objective of PF policy is to maximize the logarithmic sum of long term averaged user rate, equally, the geometric mean rate (GMR). To achieve this aim, the user scheduling and power allocation need to maximize the following criteria in each frame [11]:

$$\prod_{m=1}^{M} \left[1 + \sum_{k=1}^{K} \frac{x_{m,k}(t)\, r_{m,k}(t)}{(t_c - 1) R_m(t)} \right]. \tag{7}$$

When $t_c \gg 1$, it can be approximated as

$$1 + \frac{1}{t_c - 1} \sum_{k=1}^{K} \sum_{m=1}^{M} x_{m,k}(t) \left[\frac{r_{m,k}(t)}{R_m(t)} \right]. \tag{8}$$

Accordingly, we define the scheduling factor for the PF-based NOMA system as

$$\omega_k(t) = \sum_{m=1}^{M} x_{m,k}(t) \left[\frac{r_{m,k}(t)}{R_m(t)} \right], \quad k = 1, ..., K. \tag{9}$$

Thus, one or two users need to be selected from $\mathbf{U}_M$ for each RB and assigned appropriate transmit power in order to obtain the maximum $\omega_k(t)$.

B. Proposed User Pair Power Allocation Scheme

Here we will describe our proposed power allocation scheme. Focusing on the PA problem, we neglect the marks t and k in (9). Without loss of generality, we consider users 1 and 2 in $\mathbf{U}_M$ as a candidate scheduled user pair and optimize their power allocation. Thus, the scheduling factor in (9) can be rewritten as a function of the power ratio for the 2-user scheduled case, i.e.,

$$\omega(\lambda_1) = \frac{r_1(\lambda_1)}{R_1} + \frac{r_2(1 - \lambda_1)}{R_2}. \tag{10}$$

1) Prerequisite for user pairing: We assume that user 1 has a CQI no smaller than user 2, i.e., $\phi_1 \geq \phi_2$. So user 1 needs to carry out SIC process for its data reception. Considering the MCS selection, the power ratios of both user 1 and 2 cannot be too low, which means that λ_1 is not allowed to be close to 0 or 1. We denote the minimum required PSINR threshold as β_0 while the MCS with the lowest coding rate is selected for an expected BLER. Firstly, the requirement for the PSINR of the user 2 is given as

$$\Phi_2 = \frac{(1 - \lambda_1)\phi_2}{\lambda_1 \phi_2 + 1} \geq \beta_0. \tag{11}$$

Hence, the power ratio λ_1 obeys

$$\lambda_1 \leq \frac{\phi_2 - \beta_0}{\phi_2 (1 + \beta_0)} \triangleq \lambda_1^u, \tag{12}$$

where λ_1^u is defined as the upper bound of λ_1. Due to $\lambda_1 > 0$,

$$\lambda_1^u > 0 \quad \Leftrightarrow \quad \phi_2 > \beta_0 > 0. \tag{13}$$

Similarly the PSINR of user 1 after SIC should also be larger than the minimum request of the MCS selection, i.e.,

$$\lambda_1 \phi_1 \geq \beta_0 \quad \Rightarrow \quad \lambda_1 \geq \beta_0 \phi_1^{-1} \triangleq \lambda_1^l, \tag{14}$$

where λ_1^l is defined as the lower bound of λ_1, and we have

$$\lambda_1^l < 1 \quad \Leftrightarrow \quad \phi_1 > \beta_0 > 0. \tag{15}$$

Also considering the existence of λ_1 in the range of $[\lambda_1^l, \lambda_1^u]$, it holds that

$$\lambda_1^l \leq \lambda_1^u. \tag{16}$$

As a result, the prerequisites for a possible scheduled user pair based on SIC include (13), (15) and (16). If any conditions among them are not satisfied by a candidate user pair, the computation and comparison of their PF scheduling factor in (10) can be omitted. So the compared amount of user pairs can be reduced and is less than the maximum one, i.e., C_M^2.

2) Optimal solution of user power allocation: We relax the MCS constraint for the instantaneous user rate calculation in (6) by using $\eta = \log_2(1 + \Phi)$ as the achievable symbol bitrate according to the Shannon capacity. So we derive $\omega(\lambda_1)$ in (10) as

$$\omega(\lambda_1) = \frac{r_0}{R_1} \log_2(1 + \lambda_1 \phi_1) + \frac{r_0}{R_2} \log_2 \left(\frac{\phi_2}{\lambda_1 \phi_2 + 1} \right). \tag{17}$$

The derivative of $\omega(\lambda_1)$ is derived as

$$\omega'(\lambda_1) = \frac{r_0}{\ln 2} \left[\frac{\phi_1}{R_1 (1 + \lambda_1 \phi_1)} - \frac{\phi_2}{R_2 (1 + \lambda_1 \phi_2)} \right]. \tag{18}$$

Let $\omega'(\lambda_1) = 0$. The solution of this equation depends on the relationship of R_1 and R_2 and will be derived as follows.

Case 1: While $R_1 \neq R_2$, we have the solution of the stationary point of $\omega(\lambda_1)$ as follows,

$$\lambda_1^* = \frac{R_1/\phi_1 - R_2/\phi_2}{R_2 - R_1}. \tag{19}$$

When $\lambda_1^* \geq 0$, the following relationship holds

$$R_1 \phi_2 / \phi_1 \leq R_2 < R_1. \tag{20}$$

According to this relationship, the second derivative of $\omega(\lambda_1)$ while $\lambda_1 = \lambda_1^*$ is calculated as follows,

$$\omega''(\lambda_1^*) = \frac{r_0 \phi_1^2 \phi_2^2 (R_1 - R_2)^2}{\ln 2 R_1 R_2 (\phi_1 - \phi_2)^2} \left(\frac{1}{R_1} - \frac{1}{R_2} \right) < 0. \tag{21}$$

Therefore, $\omega(\lambda_1^*)$ is a maximum point when $\lambda_1^* \geq 0$. Since $\omega(\lambda_1)$ is continuous differentiable when $\lambda_1 \geq 0$ and there is only one maximum point, $\omega(\lambda_1)$ is monotone increasing when $0 \leq \lambda_1 \leq \lambda_1^*$, and $\omega(\lambda_1)$ is monotone decreasing when $\lambda_1 \geq \lambda_1^*$. Thus, there are three cases of the optimal power ratio, denoted as $\hat{\lambda}_1$, in the range of $[\lambda_1^l, \lambda_1^u]$ as follows:

- If $\lambda_1^l \leq \lambda_1^* \leq \lambda_1^u$, then $\hat{\lambda}_1 = \lambda_1^*$.
- If $\lambda_1^* > \lambda_1^u$, then $\hat{\lambda}_1 = \lambda_1^u$.

- If $0 \leq \lambda_1^* < \lambda_1^l$, then $\hat{\lambda}_1 = \lambda_1^l$.

When $\lambda_1^* < 0$, the following relationships hold according to (19)

$$R_1/\phi_1 > R_2/\phi_2, \quad \text{or} \quad R_2 > R_1. \tag{22}$$

Based on the two cases in (22), we solve the optimal power ratios when $\lambda_1^* < 0$ as follows:

- If $R_1/\phi_1 > R_2/\phi_2$, we have $\omega'(\lambda_1) < 0$ according to (18). Therefore, the optimal power ratio $\hat{\lambda}_1 = \lambda_1^l$.
- If $R_2 > R_1$, $\omega'(\lambda_1) > 0$. So the optimal power ratio $\hat{\lambda}_1 = \lambda_1^u$.

Case 2: While $R_1 = R_2$, it holds that

$$\omega''(\lambda_1) = \frac{r_0}{R_1 \ln 2}\left(\frac{\phi_1}{(1+\lambda_1\phi_1)} - \frac{\phi_2}{(1+\lambda_1\phi_2)}\right) \geq 0. \tag{23}$$

Therefore, the optimal solution is $\hat{\lambda}_1 = 1$. This means that user 1 occupies all power, which is the repeated case in single user scheduling. So $R_1 \neq R_2$ should also be considered as the prerequisite for user pairing along with (13), (15) and (16).

According to the above derivation, we summarize the solution of optimal power ratio $\hat{\lambda}_1$ for the 2-user PF-based NOMA as follows.

$$\hat{\lambda}_1 = \begin{cases} \lambda_1^*, & \lambda_1^l \leq \lambda_1^* \leq \lambda_1^u, \\ \lambda_1^u, & \lambda_1^u \leq \lambda_1^*, \text{ or } R_1 < R_2, \\ \lambda_1^l, & \text{others.} \end{cases} \tag{24}$$

According to (24) we can calculate the obtainable scheduling factor of every valid pair of users and select the largest one. The computational complexity of the power allocation of our proposed scheme is significantly reduced in comparison with the FAPA, TTPA, and IWF-based PA methods. This is due to the fact that the optimal power ratio can be directly calculated without any searching or iteration.

IV. Simulation and Results

In this section the performance of our proposed PA scheme is evaluated with system-level simulations. We consider a downlink cellular network with 37 cells deployed in a hexagonal grid pattern for the simulation. The simulation parameters are listed in Table I [10]. To avoid the edge effect, only the performance of the central cell is computed and other 36 BSs act as interferers. User terminals are uniformly randomly distributed. The target BLER for MCS selection is 10% [12]. The time averaged user rates are initialized randomly, and the performance statistics compute 5,000 frames and begin after 1,000 frames when the system status is stable. We use our proposed UPPA scheme for NOMA and compare its performance with OFDMA. The TTPA scheme is also evaluated, which is verified to outperform FTPA with reduced searching cost than FSPA [4]. The IWF-based PA method is not evaluated here due to its weakness of impracticability discussed in [4] and high computational complexity of the iteration algorithm [6].

Fig. 2 presents the throughput performance of both the NOMA and OFDMA systems in terms of GMR, arithmetic mean rate (AMR) and cell-edge user rate (CER). CER is defined as the time averaged user rate at the 5th percentile of the lowest ones. The OFDMA system can be regarded as a special case of NOMA while $N_{max} = 1$, namely, only one user can be scheduled in a RB with full power of the RB. The simulation results reveal that the performance of the NOMA system is better than the OFDMA system in all respects. Therefore, the PF-based NOMA system has higher efficiency and user fairness than the OFDMA system. As the number of users increases, all the performance decreases because there are fewer RBs obtainable per user.

In order to further compare the PA schemes in NOMA, we calculate the performance gain of the NOMA system over OFDMA, which is shown in Fig. 3. The performance gain increases while there are more users in the cell, owing to the user diversity gain brought by PF scheduling. The TTPA scheme has lower performance gains than the proposed UPPA one. This is because of the defect of its power allocation metric, which is defined as the product of the achievable spectrum efficiencies of the scheduled users. This only improves the geometric mean value of instantaneous user rates, but is not consistent with the PF scheduling factor in (9), resulting in a suboptimal PA.

We compute the user pairing probabilities by using the

TABLE I
Simulation Parameters

Parameter	Value
Inter site distance	500 m
Minimum distance from a user to BS	20 m
Bandwidth	10 MHz @ 1800 MHz
BS Transmit power (P_t)	46 dBm
BS Transmit antenna gain	18 dBi
Path loss	138.47+38.22log(R[km])
Standard deviation of shadow fading	8 dB
Fast fading	Rayleigh model
Noise power density	-174 dBm/Hz
Noise figure	9 dB
Number of RBs (K)	50
Number of subcarriers (N_{sc})	12 per RB
Number of effective symbols (S_e)	10 per frame
Frame duration (T_s)	1 ms
Averaging window size (t_c)	100
User number per cell (M)	2,4,6,8,10,20,30,40,50

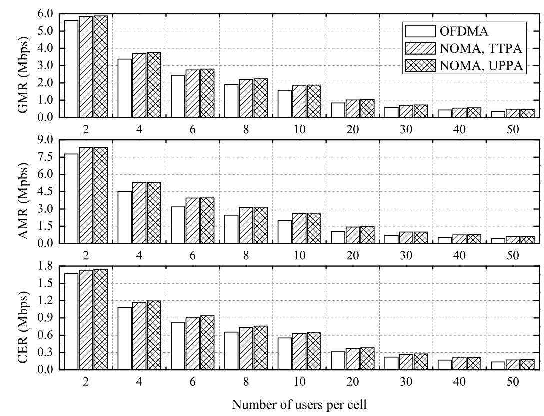

Fig. 2. Comparison of throughput performance in NOMA and OFDMA.

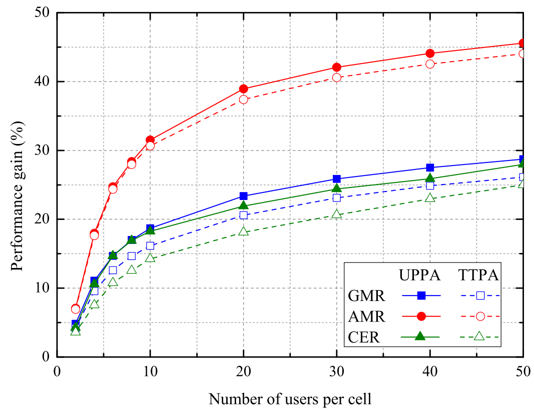

Fig. 3. Performance gains with different power allocation schemes.

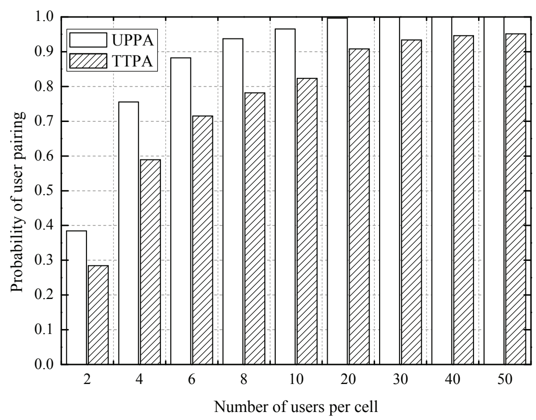

Fig. 4. Probabilities of user pairing with different power allocation schemes.

UPPA and TTPA schemes, as shown in Fig. 4. The UPPA scheme results in a higher probability of user pairing, i.e., the case of 2 user scheduled simultaneously by NOMA. When there are more than 20 users, the probability becomes 1 with UPPA, which means there is no user scheduled alone as in OFDMA.

The average number of compared candidate user pairs per RB during each frame is computed and presented in Fig. 5. The full amount of candidate user pairs is C_M^2 when there are M users. However, considering the prerequisites for PA as we analyzed in section III, this number can be reduced by nearly 15% in our proposed scheme. On the other hand, since the TTPA scheme is a searching-based optimization, the complexity of the metric calculation of each user pair is much higher than the directly computed optimal solution in UPPA.

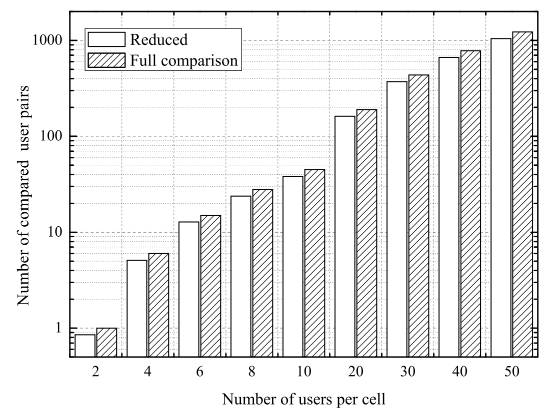

Fig. 5. The average number of compared candidate user pairs per RB.

V. Conclusion

In this paper we have focused on the user pairing and power allocation in the 2-user NOMA system and proposed the UPPA scheme based on the optimal closed-form solution with the PF objective. The prerequisites for user pairing were formulated in order to remove invalid candidate user pairs. Simulation results verified that the proposed UPPA scheme improves the performance gains of NOMA over OFDMA in terms of both efficiency and user fairness. It also outperforms TTPA with much lower computational complexity and helps enhancing the chances of user pairing in NOMA systems. One promising future extension of this work is the PA scheme in the multi-user NOMA system where more than 2 users are allowed to be scheduled by NOMA.

Acknowledgements

We thank the financial support from the German Research Foundation (DFG) through UMIC Research Centre and Excellence Initiative.

References

[1] S. Chen and J. Zhao, "The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication," *IEEE Communication Magazine*, vol. 52, no. 5, pp. 36-43, May 2014.
[2] A. Benjebbour, et al., "Concept and practical considerations of non-orthogonal multiple access (NOMA) for future radio access," in *Proc. of ISPACS 2013*, pp. 770-774, Nov. 2013.
[3] Y. Saito, et al., "Non-orthogonal multiple access for cellular future radio access," in *Proc. of IEEE VTC 2013 Spring*, pp. 1-5, Jun. 2013.
[4] A. Li, A. Harada, and H. Kayama, "A novel low computational complexity power allocation method for non-orthogonal multiple access systems," *IEICE Trans. Fundamentals*, vol. E97-A, no. 1, pp. 57-67, Jan. 2014.
[5] Y. Saito, A. Benjebbour, Y. Kishiyama, and T. Nakamura, "System-level performance evaluation of downlink non-orthogonal multiple access (NOMA)," in *Proc. of PIMRC 2013*, pp 611-615, Sep. 2013.
[6] N. Otao, Y. Kishiyama, and K. Higuchi, "Performance of non-orthogonal access with sic in cellular downlink using proportional fair-based resource allocation," in *Proc. of ISWCS 2012*, pp. 476-480, Aug. 2012.
[7] A. Benjebbour, et al., "System-level performance of downlink NOMA for future LTE enhancements," in *Proc. of IEEE Globecom Workshops 2013*, pp. 66-77, Dec. 2013.
[8] N. Nonaka, Y. Kishiyama, and K. Higuchi, "Non-orthogonal multiple access using intra-beam superposition coding and SIC in base station cooperative MIMO cellular downlink," in *Proc. of IEEE VTC 2014 Fall*, pp. 1-5, Sep. 2014.
[9] S. Timotheou and I. Krikidis, "Fairness for non-orthogonal multiple access in 5G systems," arXiv:1504.02300v1 [cs.IT], Apr. 2015.
[10] 3GPP, LTE; Evolved universal terrestrial radio access (E-UTRA); Physical channels and modulation, TS 36.211, V 11.5.0, Jan. 2014.
[11] H. Kim, K. Kim, Y. Han, and S. Yun, "A proportional fair scheduling for multicarrier transmission systems," in *Proc. of IEEE VTC 2004 Fall*, pp. 409-413, Sep. 2014.
[12] J. Fan et al., "MCS selection for throughput improvement in downlink LTE systems," in *Proc. of ICCCN 2011*, pp. 1-5, Aug. 2011.